

## PATENT ABSTRACTS OF JAPAN

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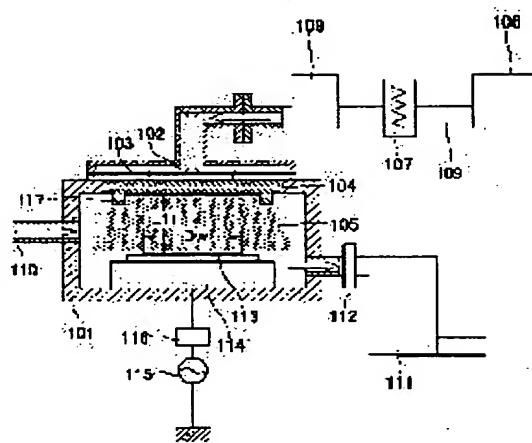
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## (54) APPARATUS AND METHOD FOR MICROWAVE PLASMA TREATMENT

## (57)Abstract:

**PROBLEM TO BE SOLVED:** To provide an apparatus and a method for microwave plasma treatment wherein uniform plasma density is attained on the surfaces of substrates and efficient plasma treatment is performed with reliability and stability.

**SOLUTION:** A dielectric window which has an annular sleeve on the periphery thereof and wherein the surface shape and the thickness of the central portion thereof are adjusted in plane is used for a dielectric window placed directly above the surface of a substrate. This in-plane adjustment is made by forming stepped portions by forming projected portions in areas of the dielectric window corresponding to a specified range of the radius in the substrate, or forming recessed portions in areas corresponding to the projected portions on the surface opposite the surface on which the projected portions are formed. The thickness of the portions of the dielectric window subjected to the in-plane adjustment is approx.  $1/4$  of the wavelength of microwaves in the dielectric, and the portions subjected to the in-plane adjustment are discontinuously formed in the direction of the radius of the dielectric window with a diameter equivalent to an integral multiple of  $1/2$  the wavelength.



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CLAIMS

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[Claim(s)]

[Claim 1] The exhaust air means for decompressing the inside of a microwave plasma treatment container, and the gas supply means for supplying the gas for exciting the plasma in this processing container, The dielectric window for microwave transparency prepared in the wall surface of this processing container, and the antenna means formed in the microwave installation side of this dielectric window, In the microwave plasma treatment equipment constituted so that it may have the microwave generating means formed in the upstream of this antenna means, this dielectric window may be countered and a substrate may be installed in this processing container This dielectric window prepared in right above on this front face of a substrate is microwave plasma treatment equipment characterized by having the ring-like sleeve so that a plasma excitation field may not contact the surface of metal of a direct-processing vessel wall at the periphery section of the field by the side of the processing container.

[Claim 2] The dielectric window prepared in right above on said front face of a substrate is microwave plasma treatment equipment according to claim 1 characterized by adjusting the shape of surface type and thickness of the center section in a field, and being further constituted so that it may have the thickness in which the field corresponding to the predetermined range of the radius in this substrate differed from other fields.

[Claim 3] The dielectric window prepared in right above on said front face of a substrate Furthermore, it sets to one field of the field by the side of the processing container, and the fields by the side of microwave installation. [ whether it is constituted so that heights may be prepared in the field corresponding to the predetermined range of the radius in this substrate and the thickness of the field corresponding to the predetermined range of the radius in this substrate may become thicker than the thickness of other fields, and ] Or microwave plasma treatment equipment according to claim 1 characterized by establishing a crevice in this field corresponding to heights of a field and the field of an opposite hand in which these heights were prepared, and being constituted so that the thickness of the prepared field of these heights and a crevice may become the same as the thickness of other fields.

[Claim 4] Microwave plasma treatment equipment according to claim 1 characterized by preparing a concentric circular level difference in the dielectric window prepared in right above on said front face of a substrate, making it the distance from this substrate front face to the front face of this dielectric window change with range of the radius in a substrate, and making it the consistency of the plasma to generate become homogeneity on this substrate.

[Claim 5] Microwave plasma treatment equipment according to claim 4 characterized by preparing discontinuously the concentric circular level difference of the dielectric window prepared in right above on said front face of a substrate for the diameter of 1/2 wave of integral multiple in the direction of a path of this dielectric window.

[Claim 6] Microwave plasma treatment equipment according to claim 2 to 5 which has the field where the dielectric window prepared in right above on said front face of a substrate has the thickness from which the center section differed, the field which has heights, and the field which has a concentric circular level difference, and is characterized by the thickness of the field being about [ of the wavelength of the microwave in a dielectric ] 1/4.

[Claim 7] The material gas for exciting the plasma with a gas supply means is supplied in a microwave plasma treatment container. Exhaust a raw material and reaction secondary generation gas with an exhaust air pump, and the inside of a container is made reduced pressure. Introduce into an antenna means the microwave made to oscillate and amplify with a microwave generating means, and it emanates through a slot. The emitted microwave is introduced into this processing container under a vacuum ambient atmosphere through a microwave transparency aperture. As this dielectric window that generated the plasma, consisted of carrying out microwave plasma treatment of the substrate which countered this dielectric window and was formed, and was prepared in the processing container by the electromagnetic field which this microwave makes right above on this front face of a substrate So that a plasma excitation field may not contact the surface of metal of a direct-processing vessel wall at the periphery section of the field by the side of the processing container Have the ring-like sleeve and the shape of surface type and thickness of the center section are further adjusted in a field. [ whether it is constituted so that it may have the thickness in which the field corresponding to the predetermined range of the radius in this substrate differed from other fields, and ] Or it sets to one field of the field by the side of the processing container, and the fields by the side of microwave installation. [ whether it is constituted so that heights may be prepared in the field corresponding to the predetermined range of the radius in this substrate and the thickness of the field corresponding to the predetermined range of the radius in this substrate may become thicker than the thickness of other fields, and ] Or a crevice is established in this field corresponding to heights of a field and the field of an opposite hand in which these heights were prepared. The microwave plasma treatment approach characterized by performing plasma treatment using plasma treatment equipment equipped with the dielectric window constituted so that the thickness of the prepared field of these heights and a crevice may become the same as the thickness of other fields.

[Claim 8] The microwave plasma treatment approach according to claim 7 characterized by performing plasma treatment as the consistency of the plasma to generate becomes homogeneity on a substrate using plasma treatment equipment equipped with the dielectric window which prepared the concentric circular level difference discontinuously for the diameter of  $1/2$  wave of integral multiple in the direction of a path of this dielectric window as said dielectric window.

[Claim 9] The microwave plasma treatment approach according to claim 7 or 8 characterized by performing plasma treatment using plasma treatment equipment equipped with the dielectric window which has the field which has the thickness from which the center section differed as said dielectric window, the field which has heights, and the field which has a concentric circular level difference, and made thickness of the field about [ of the wavelength of the microwave in a dielectric ]  $1/4$ .

[Claim 10] The frequency of the microwave which said gas pressure in said processing container is 0.1Pa – 1000Pa, and is impressed to an electrode is the microwave plasma treatment approach according to claim 7 to 9 characterized by being 2GHz – 10GHz.

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DETAILED DESCRIPTION

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[Detailed Description of the Invention]

[0001]

[Field of the Invention] This invention relates to the microwave plasma-treatment equipment which is microwave plasma-treatment equipment which has the microwave installation aperture of the large power flux density of 0.5 W/cm<sup>2</sup> - 20 W/cm<sup>2</sup> especially, and can perform improvement and refining of membrane formation, etching, and a film presentation, and ashing to the substrate which is a processed material in semi-conductor LSI production, and the plasma-treatment approach using this equipment with respect to the plasma-treatment approach of using microwave-excitation plasma-treatment equipment (microwave plasma-treatment equipment being called hereafter.) and this equipment.

[0002]

[Description of the Prior Art] In recent years, as for micro processing of a wafer, sheet processing is in use with diameter[ of macrostomia ]-izing of detailed-izing of the device in Semi-conductor LSI, and a wafer. In the plasma treatment of CVD in it, etching, or ashing, the source of the plasma of DC or high-frequency excitation is used. Moreover, ECR (electron cyclotron resonance) is used in the source of the plasma using microwave. In the case of the plasma excited by the RF or ECR as mentioned above, it was difficult to generate the uniform plasma with the diameter of macrostomia the top to be impressed [ of a magnetic field ] in order to generate the plasma of high density. Moreover, since plasma potential was as high as about 20eV, sputtering of the chamber wall was carried out, and there was also a problem that metal contamination occurs, or it gave a damage further to a substrate with 10eV or more since the ion irradiation energy to a floating substrate is also high.

[0003] Then, using antenna means, such as a radial line slot antenna (RLSA is called hereafter.), microwave is introduced into a vacuum ambient atmosphere through a dielectric from a slot, and the method which generates the surface wave plasma is developed by making strong microwave electric field. For example, the method which changed the thickness of a dielectric window continuously is indicated by JP,2000-294548,A. By this method, since circularly-polarized-wave microwave is emitted with the slot pattern of an antenna, the uniform plasma is generable with the diameter of macrostomia, and since the frequency is high, the plasma of low temperature and high density can be generated, and it is supposed that good plasma treatment will be realizable at high speed.

[0004]

[Problem(s) to be Solved by the Invention] Although microwave spreads waveguide by a certain specific mode, and it emanates from an antenna means, and microwave electric field are made and the plasma is formed by it in a vacuum housing with the conventional technique given [ said ] in JP,2000-294548,A, if the plasma becomes high density, microwave will be reflected on a plasma front face at the same time energy-absorbing happens, and it will generate between the antenna front faces and the plasma excitation sections into which many and unspecified modes inserted the dielectric. Thus, the thickness of a dielectric window is changed continuously, and when using what made the field by the side of a plasma treatment room the shape of a drill, there is a problem in the stability in the mode etc.

[0005] This reflected wave is divided into the mode which decreases between an antenna front face and the plasma excitation sections as a cavity resonator, and the mode amplified. However, if this reflected wave interferes with the introduced microwave and declines, power supply to the plasma will not be stabilized but the plasma will become instability. Consequently, stopped the reflected wave by the tuner, and it did not go out, or auto matching always shook greatly, and there was also a problem that the plasma blinked.

[0006] Moreover, microwave has the inclination which power concentrates on the part, so that a part with the plasma becomes low impedance, since the frequency is high. Furthermore, although the condition of surface wave mode having been formed in the direction of a path, and much modes having also combined this, and being stabilized most was taken, when the balance of a plasma impedance collapsed by aging, there was a problem that a mode jump was started and the repeatability of plasma distribution could not be taken. Moreover, it is greatly dependent also on a process pressure, and this surface wave mode has the phenomenon in which plasma density distribution is reversed in a center section and the periphery section, with low voltage (about 5-100Pa) and high voltage (100Pa-).

[0007] The technical problem of this invention is to solve the problem of the above-mentioned conventional technique, can obtain a uniform plasma consistency on a substrate front face, and is to offer the microwave plasma treatment equipment which can perform reliable and extremely stable efficient plasma treatment, and the art using this equipment.

[0008]

[Means for Solving the Problem] The microwave excitation plasma treatment equipment of this invention The exhaust air means for decompressing the inside of a microwave plasma treatment container, and the gas supply means for supplying the gas for exciting the plasma in this processing container, The dielectric window for microwave transparency prepared in the wall surface of this processing container, and the antenna means formed in the microwave installation side of this dielectric window, In the microwave plasma treatment equipment constituted so that it may have the microwave generating means formed in the upstream of this antenna means, this dielectric window may be countered and a substrate may be installed in this processing container This dielectric window prepared in right above on this front face of a substrate has the ring-like sleeve so that a plasma excitation field may not contact the surface of metal of a direct-processing vessel wall at the periphery section of the field by the side of the processing container.

[0009] In the microwave excitation plasma treatment equipment of this invention, it is desirable that the shape of surface type and thickness of the center section are adjusted in a field, and the dielectric window prepared in right above on the front face of a substrate is further constituted so that it may have the thickness in which the field corresponding to the predetermined range of the radius in this substrate differed from other fields. A dielectric window is set again to one field of the field by the side of the processing container, and the fields by the side of microwave installation. [ whether it is constituted so that heights may be prepared in the field corresponding to the predetermined range of the radius in this substrate and the thickness of the field corresponding to the predetermined range of the radius in this substrate may become thicker than the thickness of other fields, and ] Or it is desirable to establish a crevice in this field corresponding to heights of a field and the field of an opposite hand in which these heights were prepared, and to be constituted so that the thickness of the prepared field of these heights and a crevice may become the same as the thickness of other fields. In the above-mentioned processor, it is desirable to prepare a concentric circular level difference in a dielectric window, to make it the distance from a substrate front face to the front face of a dielectric window change with range of the radius in a substrate, and to make it the consistency of the plasma to generate become homogeneity on a substrate.

[0010] It is desirable that the concentric circular level difference of the above-mentioned dielectric window is discontinuously prepared in the direction of a path of this dielectric window for the diameter of  $1/2$  wave of integral multiple. Moreover, it has the field where a dielectric window has the thickness from which the center section differed, the field which has heights, and the field which has a concentric circular level difference, and it is desirable that the thickness of

the field is about [ of the wavelength of the microwave in a dielectric ]  $1/4$ . According to the microwave plasma treatment equipment of this invention, it is possible to introduce the microwave of large power flux density using the dielectric window of the diameter of macrostomia, for example, the dielectric window which has the diameter of 250mm or more, or has the area more than a circle and an EQC with a diameter of 250mm.

[0011] The microwave plasma treatment approach of this invention supplies the material gas for exciting the plasma with a gas supply means in a microwave plasma treatment container. Exhaust a raw material and reaction secondary generation gas with an exhaust air pump, and the inside of a container is made reduced pressure. Introduce into an antenna means the microwave made to oscillate and amplify with a microwave generating means, and it emanates through a slot. The emitted microwave is introduced into this processing container under a vacuum ambient atmosphere through a microwave transparency aperture. Plasma treatment is carried out using plasma treatment equipment equipped with the dielectric window constituted as the plasma was generated in a processing container, and it consisted of carrying out microwave plasma treatment of the substrate which countered this dielectric window and was formed and having been described above by the electromagnetic field which this microwave makes. The gas pressure in the above-mentioned processing container is 0.1Pa - 1000Pa, and, as for the frequency of the microwave impressed to an electrode, it is desirable that it is 2GHz - 10GHz. Gas pressure is less than 0.1Pa, and if it exceeds 1000Pa, discharge starting and maintenance will become difficult. Moreover, the plasma consistency of the request by a frequency being less than 2GHz is not obtained, but if it exceeds 10GHz, the facility for power amplification will become large-scale, and also difficulty is in the handling.

[0012] According to this invention, in microwave plasma treatment equipment, as described above, adjust the shape of surface type and thickness of a dielectric window in a field, and the microwave to supply and a reflected wave by forming the field amplified within a resonator, and the field which is not so Since generating of a mode jump can be controlled with restricting the surface-wave mode which is made to concentrate power on the field amplified efficiently, and is stabilized in space, a reliable and extremely stable efficient process can be performed. Moreover, the plasma reaches whether it is small from the front face of a dielectric window, and on the substrate which is excited in the field distant in several mm with, and counters by diffusion. Attenuation of the plasma consistency by this diffusion is proportional to square of \*\*\*\* distance. By distinguishing between the configuration of a dielectric window so that the dielectric part corresponding to the field where a plasma consistency is low may be brought close to a substrate side, a uniform plasma consistency can be obtained on a substrate front face.

[0013]

[Embodiment of the Invention] Hereafter, the microwave plasma treatment equipment concerning the gestalt of operation of this invention is explained with reference to drawing 1 , and 2, 5 and 6. Drawing 1 is the sectional view showing the configuration of the outline of equipment equipped with the microwave transparency aperture which has a ring-like sleeve in the periphery section as the first embodiment of this invention in the microwave plasma treatment equipment for semi-conductor substrates which used RLSA.

[0014] In drawing 1 , a processing container for 101 to perform plasma treatment and 102 A coaxial waveguide converter and an antenna means, The slot to which 103 emits microwave, and 104 The dielectric window for microwave transparency, The plasma formed in the substrate upper part of microwave electric field in order that 105 might perform etching and membrane formation, The magnetron to which 106 oscillates microwave, and 107 An isolator, 108 a waveguide and 110 for 4E tuner and 109 The supply means of the gas for plasma formation, The pressure regulating valve to which 111 adjusts an exhaust air pump and 112 adjusts the pressure in a container 101, An RF generator for the substrate with which 113 is carried out in plasma treatment, the electrode with which 114 holds a substrate, and 115 to impress a RF to the substrate electrode 114 and a substrate 113 if needed, and 116 are the adjustment machines for taking impedance adjustment of a RF. The ring-like sleeve 117 is formed in the part which is separated from the periphery section of a dielectric window 104, i.e., a center section, so that a plasma excitation field may not contact the surface of metal of a direct-processing vessel wall.

[0015] The outline about the plasma treatment approach hereafter performed using the equipment shown in drawing 1 is explained. The gas for exciting the plasma 105 with the gas supply means 110 is supplied in the processing container 101, the exhaust air pump 111 is operated, a raw material and reaction secondary generation gas are exhausted, the inside of the processing container 101 is made reduced pressure, and a pressure regulating valve 112 adjusts the process pressure in the processing container 101. The microwave oscillated and amplified by the magnetron 106 is introduced into an antenna 102 through the 4E tuner 108, and is emitted from a slot 103. Although a reflected wave is returned to the processing container 101 side by the 4E tuner 108 at this time, about the reflected wave which cannot be adjusted, it is absorbed with the isolator 107, and has prevented returning to a magnetron 106. The microwave emitted from the slot 103 is introduced inside the processing container 101 under a vacuum ambient atmosphere through a dielectric window 104, and forms the plasma 105 in the processing container 101 by the electromagnetic field which this microwave makes.

[0016] If the consistency of the formed plasma 105 exceeds the cut-off consistency of microwave near the dielectric window 104, the trespass length of microwave will become several mm, a part of energy will be absorbed by the plasma 105 in the range of several mm in the plasma, and the remainder will be reflected. Although the density distribution of the generated plasma 105 can be adjusted to homogeneity at a flat surface depending on a slot pattern, it depends for it also on the pressure in the processing container 101 at that time, or the configuration of a dielectric window 104 greatly. Thus, by diffusion, the generated plasma 105 can reach to a substrate 113, and can perform desired plasma treatment to a substrate 113.

[0017] Drawing 2 is the sectional view showing the configuration of the outline of equipment equipped with the microwave transparency aperture which prepared heights in the field by the side of an antenna means as the second embodiment of this invention in the configuration of the microwave plasma treatment equipment for semi-conductor substrates which used RLSA. In this equipment, in the field of a concentric circle, i.e., the field from the core of a circular dielectric window to the predetermined equal distance, heights (diameter: D2) are prepared in the front face by the side of atmospheric air (microwave installation side) as a dielectric window 204 which constitutes the introductory aperture of microwave, and the dielectric window which changed the thickness of that part is used. Other configurations are the same configurations as what is shown in drawing 1, and especially about the sign in drawing, unless it refuses, the same sign as drawing 1 shows the same configuration.

[0018] The dielectric window 204 which is an introductory aperture of microwave may be produced from the thing of the same construction material as a dielectric window 104. When using a quartz plate with a thickness of 50mm, in the field of the range (D2) to  $\phi = 95\text{mm}$ , the atmospheric-air side of a dielectric window 204 is used as a convex type, and thickness for the convex part is set to 60mm. For example, the thickness of the field where the radius of a substrate is located in right above [ of it ] in the field of the range  $(D2 \times 1/2)$  from 0mm to 47.5mm is set to 60mm, and, as for the thickness of the dielectric window in right above [ of a diameter (Dw)200mm silicon substrate ], the thickness in other fields is set to 50mm.

[0019] Drawing 5 is the sectional view showing the configuration of the outline of equipment equipped with the microwave transparency aperture which prepared heights in the field by the side of the processing container 101 as the third embodiment of this invention in the configuration of the microwave plasma treatment equipment for semi-conductor substrates which used RLSA. In this equipment, as a dielectric window 504 which constitutes the introductory aperture of microwave, heights (diameter: D5) are prepared in the front face by the side of a vacuum at reverse, and the dielectric window which changed the thickness of that part is used with the case of drawing 2 in the field of a concentric circle, i.e., the field from the core of a dielectric window to the predetermined equal distance. Other configurations are the same configurations as what is shown in drawing 1, and especially about the sign in drawing, unless it refuses, the same sign as drawing 1 shows the same configuration.

[0020] The dielectric window 504 which is an introductory aperture of microwave may be produced from the thing of the same construction material as a dielectric window 104. When using a quartz plate with a thickness of 44mm, the vacuum side of a dielectric window 504 is



used as a convex type in the field of the range (D5) to  $\phi = 60\text{mm}$ , and thickness for the convex part is set to 60mm. For example, the thickness of the field where the radius of a substrate is located in right above [ of it ] in the field of the range (D5X1/2) from 0mm to 30mm is set to 60mm, and, as for the thickness of the dielectric window in right above [ of a diameter (Dw) 200mm silicon substrate ], the thickness in other fields is set to 44mm. Moreover, in the field (D5X1/2) from 0mm to 30mm, the radius of a substrate sets distance (L52) from a substrate to a dielectric plate to 40mm, and has set the distance (L51) to 56mm in other fields.

[0021] Drawing 6 is the sectional view showing the configuration of the outline of equipment equipped with the microwave transparency aperture which prepared heights in the field by the side of the processing container 101, and established the crevice in the field corresponding to these heights in the field by the side of atmospheric air as the fourth embodiment of this invention in the configuration of the microwave plasma treatment equipment for semi-conductor substrates which used RLSA. In this equipment, it is processed so that a crevice may be established in the front face by the side of microwave installation on the front face by the side of heights and a vacuum as a dielectric window 604 which constitutes the introductory aperture of microwave in the field of a concentric circle, i.e., the field from the core of a dielectric window to the predetermined equal distance, and the dielectric window constituted so that the thickness of the dielectric window itself might turn into the same thickness in every field is used. Other configurations are the same configurations as what is shown in drawing 1, and especially about the sign in drawing, unless it refuses, the same sign as drawing 1 shows the same configuration.

[0022] The dielectric window 604 which is an introductory aperture of microwave may be produced from the thing of the same construction material as a dielectric window 104. When using a quartz plate with a thickness of 50mm, the vacuum side of a dielectric window 604 is made into a concave in the field of the range (D6) to  $\phi = 60\text{mm}$ . Diameter (Dw) from a substrate 613 about the distance to the dielectric window in right above [ of a 200mm substrate ] The radius of a substrate sets the distance (L62) to 65mm in the field of the range (D6) from 0mm to 30mm, and has set the distance (L61) to 60mm in other fields. Although the pressure in the above-mentioned plasma treatment container changes with process conditions, generally it can acquire desired effectiveness in the range of 5Pa - 1000Pa. As for the distance (L11, L21, L51, L52, L61, L62) of the underside of a dielectric window, and the top face of a substrate, it is desirable to make it the range of 30mm - 120mm generally with relation, such as a plasma consistency, an oxidation rate, and thickness distribution homogeneity.

[0023] As described above, when changing the thickness of a dielectric window within the limits of predetermined, it is desirable to make the thickness into about  $\lambda_{\text{dag}}$  of the wavelength ( $\lambda_{\text{dag}}$ ) of the microwave in a dielectric / 4. Since field strength of microwave is \*\*\*\*(ed) according to the situation of the standing wave which exists there, if a center section is the optimal thickness, in the thin periphery section, a plasma consistency will become low. This is because field strength does not necessarily become strong in the thin part only by making thickness of a dielectric window thin selectively. Therefore, the thing [ as / in this invention ] which the thickness of a center section is specified and is established for the level difference of  $\lambda_{\text{dag}}/4$  of the wavelength of the microwave in a dielectric is effective. Even if arranged in the shape of [ of a concentric circle ] a ring, the range which gives the range or level difference which changes the thickness of a dielectric window was distributed suitably, and may be arranged.

[0024] In order to choose suitably from within the limits of 2GHz - 10GHz the frequency of the microwave supplied in order to generate the plasma of high density generally and to make it the plasma consistency [ directly under ] of a dielectric window reach the cut-off consistency of microwave, it is good to choose charge power from within the limits of 1 W/cm<sup>2</sup> - 5 W/cm<sup>2</sup> suitably preferably to the area under a dielectric window, and to perform a process. Although it changes as process gas with each processes, such as formation of deposition film (an insulator layer, the semi-conductor film, metal membrane, etc.), formation of the thin films (a silicon system semi-conductor thin film, a silicon compound system thin film, a metal thin film, metallic-compounds thin film, etc.) by the CVD method, etching on the front face of a substrate, ashing clearance of the organic component on a substrate front face, oxidation treatment on the front

face of a substrate, and cleaning of the organic substance on the front face of a substrate, various well-known gas can be chosen suitably and can be used. For example, what is necessary is just to introduce one or more kinds of well-known gas more than a total of  $8.5 \times 10^{-2} \text{ Pa}\cdot\text{m}^3/\text{sec}$  at least into a process.

[0025] What is necessary is just to choose it from within the limits of  $-40$  degrees C  $- 600$  degrees C suitably generally, although the support stage temperature of a substrate changes with each processes, such as etching and membrane formation. Especially the substrate made into a processing object is not restricted, for example, not only a semi-conductor substrate but a glass substrate, a plastic plate, an AlTiC substrate, etc. can be used for it. As a dielectric which constitutes the introductory aperture of microwave, a mechanical strength is enough, and especially if dielectric loss is a very small ingredient so that the permeability of microwave may become sufficiently high, it will not be restricted, for example, a quartz, an alumina (sapphire), aluminum nitride, silicon nitride, a carbon fluoride polymer, etc. can be used.

[0026]

[Example] Hereafter, the example of this invention is further explained to a detail with reference to a drawing.

(Example 1) Kr/O<sub>2</sub> plasma is generated using the equipment of this invention shown in drawing 1 and drawing 2, and measurement of the thickness of the oxide film of the processing wafer after oxidizing a silicon substrate directly is explained. Oxidation treatment of a silicon substrate which first is performed using the equipment shown in drawing 1 is explained. After installing the dielectric window 104 in the introductory aperture of microwave and setting a silicon substrate 113 in the vacuum processing container 101, microwave was outputted from the magnetron 106, the plasma was generated on condition that the following, and the thickness of the oxide film of the silicon substrate 113 after plasma oxidation was measured by the ellipsometer.

[0027] As a dielectric window 104, the quartz plate (a dielectric constant 3.8, dielectric loss  $<1.0 \times 10^{-4}$  @ 2.45GHz) with a diameter [ of 380mm (vacuum-housing side: 350mm) ] and a thickness of 50mm was installed. microwave — frequency: — 2.45GHz — output: — it was referred to as 2.5kW (about 2.6W/cm<sup>2</sup>), hot plate temperature was maintained at 400 degrees C, distance between the top face of a silicon substrate 113 and the underside of a dielectric window 104 (L11) was set to 60mm, and plasma treatment was performed, without impressing high frequency bias to the silicon substrate 113 on the substrate electrode 114. As gas for plasma excitation,  $1.7 \times 10^{-2} \text{ Pa}\cdot\text{m}^3/\text{sec}$  supply of 0.5 Pa·m<sup>3</sup>/sec and O<sub>2</sub> was carried out for Kr, by the pressure regulating valve 112, the pressure in the processing container 101 was adjusted to 133Pa, it discharged for 10 minutes, and plasma oxidation processing of a wafer was performed. Moreover, plasma treatment was performed on the same conditions as the above except having adjusted the pressure in the processing container 101 to 80Pa by the pressure regulating valve 112.

[0028] Consequently, distribution of the thickness of the silicon oxide formed on the substrate became concentric circular mostly. The average thickness of the direction of a path is shown in drawing 3. In the case of 80Pa, the periphery section on a substrate has thickness thicker than a center section, and drawing 3 shows that the oxidation rate of a center section is quicker in the case of 133Pa to a thing with a quick oxidation rate.

[0029] Next, using the equipment shown in drawing 2, on the same conditions as the case of the equipment shown in drawing 1, plasma oxidation processing of the silicon substrate 213 was carried out, and the thickness of an oxide film (oxidation silicone film) was measured by the ellipsometer. Consequently, distribution of the thickness of the silicon oxide formed on the substrate became concentric circular with homogeneity mostly. The average thickness of the direction of a path is shown in drawing 4. It turns out that that difference is small about this result although the oxidation rate of thickness distribution of the oxide film in 80Pa to the periphery section is still quicker than a center section as compared with drawing 3, and distribution homogeneity is improved. Moreover, on the whole, the formation rate of an oxide film is quick. While the power of microwave comes to be efficiently supplied to the plasma by changing the configuration of a dielectric window from this, it turns out that distribution homogeneity is improving. Also in 133Pa, on the whole, the oxidation rate is quick, and it can say

that it is the same as that of the case where it is 80Pa.

[0030] (Example 2) Kr/O<sub>2</sub> plasma is generated using the equipment shown in drawing 5 , and measurement of the thickness of the oxide film of the processing wafer after oxidizing a silicon substrate directly is explained. On the same conditions as the case of the equipment shown in drawing 1 indicated in the example 1, plasma oxidation processing of the silicon substrate 513 was carried out, and the thickness of an oxide film was measured by the ellipsometer.

[0031] Consequently, distribution of the thickness of the silicon oxide formed on the substrate became concentric circular with homogeneity mostly. The average thickness of the direction of a path is shown in drawing 7 . This result is known by that the oxidation rate is [ the center section ] quick rather than the periphery section at the case of thickness distribution of the oxide film in 80Pa to drawing 3 , and reverse as compared with drawing 3 . This is because the consistency of the plasma to which the radius of a silicon substrate reaches a substrate in the range from 0mm to 30mm since the distance (L52) to a dielectric window (plasma production field) is short is higher than other range (distance: L51). Therefore, the distribution homogeneity of thickness is improvable by the membrane formation rate in the field rising by bringing the distance from the dielectric window underside by the side of a vacuum to a substrate close for every field, and adjusting the distance.

[0032] (Example 3) Kr/O<sub>2</sub> plasma is generated using the equipment shown in drawing 6 , and measurement of the thickness of the oxide film of the processing wafer after oxidizing a silicon substrate directly is explained. On the same conditions as the case of the equipment shown in drawing 1 indicated in the example 1, plasma oxidation processing of the silicon substrate 613 was carried out, and the thickness of an oxide film was measured by the ellipsometer.

[0033] Consequently, distribution of the thickness of the silicon oxide formed on the substrate became concentric circular with homogeneity mostly. The average thickness of the direction of a path is shown in drawing 8 . It turns out that it is improved in the direction in which the oxidation rate of a center section rises, and homogeneity is going up this result from thickness distribution of the oxide film in 80Pa as compared with drawing 3 . On the other hand, it is improved in the direction in which the oxidation rate of the periphery section rises conversely in 133Pa, and homogeneity is going up. Apparently, although this is contradictory to the result of the above-mentioned example, even if the dielectric window 104 ( drawing 1 ) of a flat-surface configuration is used for it in 133Pa high voltage conditions, it has the inclination which the plasma concentrates on a center section. However, like the result in an example 2, since it is far 5mm compared with the field (distance: L61) of others [ center section / substrate / distance / (L62) / to a dielectric window (plasma production field) ], it becomes thinner than the range of others [ consistency / of the plasma which reaches a substrate ], and it is thought that distribution has been improved. On the contrary, although the plasma tends to spread in the low voltage of 80Pa since the plasma consistency is thin, the plasma production in a field concave by making into a concave a part of field which a surface wave generates increases, and it thinks because the stability coupled modes of microwave stopped being influenced easily due to the flow and pressure requirement. Therefore, the breadth of the plasma was stopped, and near distribution came to be acquired when it is high voltage conditions.

[0034] As mentioned above, by performing concavo-convex processing to both sides of a dielectric window for every field, the power of microwave was intentionally centralized on this field, and generation of the homogeneous good plasma with little [ and ] pressure dependence was attained. Although plasma oxidation processing of the silicon substrate was carried out and the oxide film was formed in the above-mentioned example using drawing 1 and the microwave plasma treatment equipment shown in 2, 5, and 6, processes, such as an improvement and refining of membrane formation, etching, and a film presentation, and ashing, were able to be performed to the substrate which is a processed material in semi-conductor LSI production using well-known thin film formation gas, an etchant gas, ashing gas, etc. using the same plasma treatment equipment.

[0035]

[Effect of the Invention] As explained to the detail above, according to this invention, it sets to microwave plasma treatment equipment. Adjust the thickness of the shape of surface type of a

dielectric window, or a dielectric window in a field, and the microwave to supply and a reflected wave by forming the field amplified within a resonator, and the field which is not so Since power can be efficiently centralized on the field amplified, and since generating of a mode jump can be controlled with restricting the surface-wave mode stabilized in space, a reliable and extremely stable efficient process can be performed. Moreover, the plasma is excited in a less than several mm field from a dielectric window, and reaches on the substrate which counters by diffusion. Attenuation of the plasma consistency by this diffusion is proportional to square of \*\*\*\* distance. A uniform plasma consistency can be obtained on a substrate front face by giving a level difference so that a substrate side may be approached in the dielectric window of the field where a consistency is low.

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**TECHNICAL FIELD**

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[Field of the Invention] This invention relates to the microwave plasma-treatment equipment which is microwave plasma-treatment equipment which has the microwave installation aperture of the large power flux density of 0.5 W/cm<sup>2</sup> - 20 W/cm<sup>2</sup> especially, and can perform improvement and refining of membrane formation, etching, and a film presentation, and ashing to the substrate which is a processed material in semi-conductor LSI production, and the plasma-treatment approach using this equipment with respect to the plasma-treatment approach of using microwave-excitation plasma-treatment equipment (microwave plasma-treatment equipment being called hereafter.) and this equipment.

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PRIOR ART

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[Description of the Prior Art] In recent years, as for micro processing of a wafer, sheet processing is in use with diameter[ of macrostomia ]-izing of detailed-izing of the device in Semi-conductor LSI, and a wafer. In the plasma treatment of CVD in it, etching, or ashing, the source of the plasma of DC or high-frequency excitation is used. Moreover, ECR (electron cyclotron resonance) is used in the source of the plasma using microwave. In the case of the plasma excited by the RF or ECR as mentioned above, it was difficult to generate the uniform plasma with the diameter of macrostomia the top to be impressed [ of a magnetic field ] in order to generate the plasma of high density. Moreover, since plasma potential was as high as about 20eV, sputtering of the chamber wall was carried out, and there was also a problem that metal contamination occurs, or it gave a damage further to a substrate with 10eV or more since the ion irradiation energy to a floating substrate is also high.

[0003] Then, using antenna means, such as a radial line slot antenna (RLSA is called hereafter.), microwave is introduced into a vacuum ambient atmosphere through a dielectric from a slot, and the method which generates the surface wave plasma is developed by making strong microwave electric field. For example, the method which changed the thickness of a dielectric window continuously is indicated by JP,2000-294548,A. By this method, since circularly-polarized-wave microwave is emitted with the slot pattern of an antenna, the uniform plasma is generable with the diameter of macrostomia, and since the frequency is high, the plasma of low temperature and high density can be generated, and it is supposed that good plasma treatment will be realizable at high speed.

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EFFECT OF THE INVENTION

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[Effect of the Invention] As explained to the detail above, according to this invention, it sets to microwave plasma treatment equipment. Adjust the thickness of the shape of surface type of a dielectric window, or a dielectric window in a field, and the microwave to supply and a reflected wave by forming the field amplified within a resonator, and the field which is not so Since power can be efficiently centralized on the field amplified, and since generating of a mode jump can be controlled with restricting the surface-wave mode stabilized in space, a reliable and extremely stable efficient process can be performed. Moreover, the plasma is excited in a less than several mm field from a dielectric window, and reaches on the substrate which counters by diffusion. Attenuation of the plasma consistency by this diffusion is proportional to square of \*\*\*\* distance. A uniform plasma consistency can be obtained on a substrate front face by giving a level difference so that a substrate side may be approached in the dielectric window of the field where a consistency is low.

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TECHNICAL PROBLEM

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[Problem(s) to be Solved by the Invention] Although microwave spreads waveguide by a certain specific mode, and it emanates from an antenna means, and microwave electric field are made and the plasma is formed by it in a vacuum housing with the conventional technique given [ said ] in JP,2000-294548,A, if the plasma becomes high density, microwave will be reflected on a plasma front face at the same time energy-absorbing happens, and it will generate between the antenna front faces and the plasma excitation sections into which many and unspecified modes inserted the dielectric. Thus, the thickness of a dielectric window is changed continuously, and when using what made the field by the side of a plasma treatment room the shape of a drill, there is a problem in the stability in the mode etc.

[0005] This reflected wave is divided into the mode which decreases between an antenna front face and the plasma excitation sections as a cavity resonator, and the mode amplified. However, if this reflected wave interferes with the introduced microwave and declines, power supply to the plasma will not be stabilized but the plasma will become instability. Consequently, stopped the reflected wave by the tuner, and it did not go out, or auto matching always shook greatly, and there was also a problem that the plasma blinked.

[0006] Moreover, microwave has the inclination which power concentrates on the part, so that a part with the plasma becomes low impedance, since the frequency is high. Furthermore, although the condition of surface wave mode having been formed in the direction of a path, and much modes having also combined this, and being stabilized most was taken, when the balance of a plasma impedance collapsed by aging, there was a problem that a mode jump was started and the repeatability of plasma distribution could not be taken. Moreover, it is greatly dependent also on a process pressure, and this surface wave mode has the phenomenon in which plasma density distribution is reversed in a center section and the periphery section, with low voltage (about 5-100Pa) and high voltage (100Pa-).

[0007] The technical problem of this invention is to solve the problem of the above-mentioned conventional technique, can obtain a uniform plasma consistency on a substrate front face, and is to offer the microwave plasma treatment equipment which can perform reliable and extremely stable efficient plasma treatment, and the art using this equipment.

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MEANS

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[Means for Solving the Problem] The microwave excitation plasma treatment equipment of this invention The exhaust air means for decompressing the inside of a microwave plasma treatment container, and the gas supply means for supplying the gas for exciting the plasma in this processing container, The dielectric window for microwave transparency prepared in the wall surface of this processing container, and the antenna means formed in the microwave installation side of this dielectric window, In the microwave plasma treatment equipment constituted so that it may have the microwave generating means formed in the upstream of this antenna means, this dielectric window may be countered and a substrate may be installed in this processing container This dielectric window prepared in right above on this front face of a substrate has the ring-like sleeve so that a plasma excitation field may not contact the surface of metal of a direct-processing vessel wall at the periphery section of the field by the side of the processing container.

[0009] In the microwave excitation plasma treatment equipment of this invention, it is desirable that the shape of surface type and thickness of the center section are adjusted in a field, and the dielectric window prepared in right above on the front face of a substrate is further constituted so that it may have the thickness in which the field corresponding to the predetermined range of the radius in this substrate differed from other fields. A dielectric window is set again to one field of the field by the side of the processing container, and the fields by the side of microwave installation. [ whether it is constituted so that heights may be prepared in the field corresponding to the predetermined range of the radius in this substrate and the thickness of the field corresponding to the predetermined range of the radius in this substrate may become thicker than the thickness of other fields, and ] Or it is desirable to establish a crevice in this field corresponding to heights of a field and the field of an opposite hand in which these heights were prepared, and to be constituted so that the thickness of the prepared field of these heights and a crevice may become the same as the thickness of other fields. In the above-mentioned processor, it is desirable to prepare a concentric circular level difference in a dielectric window, to make it the distance from a substrate front face to the front face of a dielectric window change with range of the radius in a substrate, and to make it the consistency of the plasma to generate become homogeneity on a substrate.

[0010] It is desirable that the concentric circular level difference of the above-mentioned dielectric window is discontinuously prepared in the direction of a path of this dielectric window for the diameter of  $1/2$  wave of integral multiple. Moreover, it has the field where a dielectric window has the thickness from which the center section differed, the field which has heights, and the field which has a concentric circular level difference, and it is desirable that the thickness of the field is about [ of the wavelength of the microwave in a dielectric ]  $1/4$ . According to the microwave plasma treatment equipment of this invention, it is possible to introduce the microwave of large power flux density using the dielectric window of the diameter of macrostomia, for example, the dielectric window which has the diameter of 250mm or more, or has the area more than a circle and an EQC with a diameter of 250mm.

[0011] The microwave plasma treatment approach of this invention supplies the material gas for exciting the plasma with a gas supply means in a microwave plasma treatment container. Exhaust

a raw material and reaction secondary generation gas with an exhaust air pump, and the inside of a container is made reduced pressure. Introduce into an antenna means the microwave made to oscillate and amplify with a microwave generating means, and it emanates through a slot. The emitted microwave is introduced into this processing container under a vacuum ambient atmosphere through a microwave transparency aperture. Plasma treatment is carried out using plasma treatment equipment equipped with the dielectric window constituted as the plasma was generated in a processing container, and it consisted of carrying out microwave plasma treatment of the substrate which countered this dielectric window and was formed and having been described above by the electromagnetic field which this microwave makes. The gas pressure in the above-mentioned processing container is 0.1Pa – 1000Pa, and, as for the frequency of the microwave impressed to an electrode, it is desirable that it is 2GHz – 10GHz. Gas pressure is less than 0.1Pa, and if it exceeds 1000Pa, discharge starting and maintenance will become difficult. Moreover, the plasma consistency of the request by a frequency being less than 2GHz is not obtained, but if it exceeds 10GHz, the facility for power amplification will become large-scale, and also difficulty is in the handling.

[0012] According to this invention, in microwave plasma treatment equipment, as described above, adjust the shape of surface type and thickness of a dielectric window in a field, and the microwave to supply and a reflected wave by forming the field amplified within a resonator, and the field which is not so Since generating of a mode jump can be controlled with restricting the surface-wave mode which is made to concentrate power on the field amplified efficiently, and is stabilized in space, a reliable and extremely stable efficient process can be performed. Moreover, the plasma reaches whether it is small from the front face of a dielectric window, and on the substrate which is excited in the field distant in several mm with, and counters by diffusion. Attenuation of the plasma consistency by this diffusion is proportional to square of \*\*\*\* distance. By distinguishing between the configuration of a dielectric window so that the dielectric part corresponding to the field where a plasma consistency is low may be brought close to a substrate side, a uniform plasma consistency can be obtained on a substrate front face.

[0013]

[Embodiment of the Invention] Hereafter, the microwave plasma treatment equipment concerning the gestalt of operation of this invention is explained with reference to drawing 1, and 2, 5 and 6. Drawing 1 is the sectional view showing the configuration of the outline of equipment equipped with the microwave transparency aperture which has a ring-like sleeve in the periphery section as the first embodiment of this invention in the microwave plasma treatment equipment for semi-conductor substrates which used RLSA.

[0014] In drawing 1, a processing container for 101 to perform plasma treatment and 102 A coaxial waveguide converter and an antenna means, The slot to which 103 emits microwave, and 104 The dielectric window for microwave transparency, The plasma formed in the substrate upper part of microwave electric field in order that 105 might perform etching and membrane formation, The magnetron to which 106 oscillates microwave, and 107 An isolator, 108 a waveguide and 110 for 4E tuner and 109 The supply means of the gas for plasma formation, The pressure regulating valve to which 111 adjusts an exhaust air pump and 112 adjusts the pressure in a container 101, An RF generator for the substrate with which 113 is carried out in plasma treatment, the electrode with which 114 holds a substrate, and 115 to impress a RF to the substrate electrode 114 and a substrate 113 if needed, and 116 are the adjustment machines for taking impedance adjustment of a RF. The ring-like sleeve 117 is formed in the part which is separated from the periphery section of a dielectric window 104, i.e., a center section, so that a plasma excitation field may not contact the surface of metal of a direct-processing vessel wall.

[0015] The outline about the plasma treatment approach hereafter performed using the equipment shown in drawing 1 is explained. The gas for exciting the plasma 105 with the gas supply means 110 is supplied in the processing container 101, the exhaust air pump 111 is operated, a raw material and reaction secondary generation gas are exhausted, the inside of the processing container 101 is made reduced pressure, and a pressure regulating valve 112 adjusts the process pressure in the processing container 101. The microwave oscillated and amplified by the magnetron 106 is introduced into an antenna 102 through the 4E tuner 108, and is emitted

from a slot 103. Although a reflected wave is returned to the processing container 101 side by the 4E tuner 108 at this time, about the reflected wave which cannot be adjusted, it absorbed with the isolator 107, and has prevented returning to a magnetron 106. The microwave emitted from the slot 103 is introduced inside the processing container 101 under a vacuum ambient atmosphere through a dielectric window 104, and forms the plasma 105 in the processing container 101 by the electromagnetic field which this microwave makes.

[0016] If the consistency of the formed plasma 105 exceeds the cut-off consistency of microwave near the dielectric window 104, the trespass length of microwave will become several mm, a part of energy will be absorbed by the plasma 105 in the range of several mm in the plasma, and the remainder will be reflected. Although the density distribution of the generated plasma 105 can be adjusted to homogeneity at a flat surface depending on a slot pattern, it depends for it also on the pressure in the processing container 101 at that time, or the configuration of a dielectric window 104 greatly. Thus, by diffusion, the generated plasma 105 can reach to a substrate 113, and can perform desired plasma treatment to a substrate 113.

[0017] Drawing 2 is the sectional view showing the configuration of the outline of equipment equipped with the microwave transparency aperture which prepared heights in the field by the side of an antenna means as the second embodiment of this invention in the configuration of the microwave plasma treatment equipment for semi-conductor substrates which used RLSA. In this equipment, in the field of a concentric circle, i.e., the field from the core of a circular dielectric window to the predetermined equal distance, heights (diameter: D2) are prepared in the front face by the side of atmospheric air (microwave installation side) as a dielectric window 204 which constitutes the introductory aperture of microwave, and the dielectric window which changed the thickness of that part is used. Other configurations are the same configurations as what is shown in drawing 1, and especially about the sign in drawing, unless it refuses, the same sign as drawing 1 shows the same configuration.

[0018] The dielectric window 204 which is an introductory aperture of microwave may be produced from the thing of the same construction material as a dielectric window 104. When using a quartz plate with a thickness of 50mm, in the field of the range (D2) to  $\phi = 95\text{mm}$ , the atmospheric-air side of a dielectric window 204 is used as a convex type, and thickness for the convex part is set to 60mm. For example, the thickness of the field where the radius of a substrate is located in right above [ of it ] in the field of the range (D2X1/2) from 0mm to 47.5mm is set to 60mm, and, as for the thickness of the dielectric window in right above [ of a diameter (Dw)200mm silicon substrate ], the thickness in other fields is set to 50mm.

[0019] Drawing 5 is the sectional view showing the configuration of the outline of equipment equipped with the microwave transparency aperture which prepared heights in the field by the side of the processing container 101 as the third embodiment of this invention in the configuration of the microwave plasma treatment equipment for semi-conductor substrates which used RLSA. In this equipment, as a dielectric window 504 which constitutes the introductory aperture of microwave, heights (diameter: D5) are prepared in the front face by the side of a vacuum at reverse, and the dielectric window which changed the thickness of that part is used with the case of drawing 2 in the field of a concentric circle, i.e., the field from the core of a dielectric window to the predetermined equal distance. Other configurations are the same configurations as what is shown in drawing 1, and especially about the sign in drawing, unless it refuses, the same sign as drawing 1 shows the same configuration.

[0020] The dielectric window 504 which is an introductory aperture of microwave may be produced from the thing of the same construction material as a dielectric window 104. When using a quartz plate with a thickness of 44mm, the vacuum side of a dielectric window 504 is used as a convex type in the field of the range (D5) to  $\phi = 60\text{mm}$ , and thickness for the convex part is set to 60mm. For example, the thickness of the field where the radius of a substrate is located in right above [ of it ] in the field of the range (D5X1/2) from 0mm to 30mm is set to 60mm, and, as for the thickness of the dielectric window in right above [ of a diameter (Dw) 200mm silicon substrate ], the thickness in other fields is set to 44mm. Moreover, in the field (D5X1/2) from 0mm to 30mm, the radius of a substrate sets distance (L52) from a substrate to a dielectric plate to 40mm, and has set the distance (L51) to 56mm in other fields.

[0021] Drawing 6 is the sectional view showing the configuration of the outline of equipment equipped with the microwave transparency aperture which prepared heights in the field by the side of the processing container 101, and established the crevice in the field corresponding to these heights in the field by the side of atmospheric air as the fourth embodiment of this invention in the configuration of the microwave plasma treatment equipment for semi-conductor substrates which used RLSA. In this equipment, it is processed so that a crevice may be established in the front face by the side of microwave installation on the front face by the side of heights and a vacuum as a dielectric window 604 which constitutes the introductory aperture of microwave in the field of a concentric circle, i.e., the field from the core of a dielectric window to the predetermined equal distance, and the dielectric window constituted so that the thickness of the dielectric window itself might turn into the same thickness in every field is used. Other configurations are the same configurations as what is shown in drawing 1, and especially about the sign in drawing, unless it refuses, the same sign as drawing 1 shows the same configuration.

[0022] The dielectric window 604 which is an introductory aperture of microwave may be produced from the thing of the same construction material as a dielectric window 104. When using a quartz plate with a thickness of 50mm, the vacuum side of a dielectric window 604 is made into a concave in the field of the range (D6) to  $\phi = 60\text{mm}$ . Diameter (Dw) from a substrate 613 about the distance to the dielectric window in right above [ of a 200mm substrate ] The radius of a substrate sets the distance (L62) to 65mm in the field of the range (D6) from 0mm to 30mm, and has set the distance (L61) to 60mm in other fields. Although the pressure in the above-mentioned plasma treatment container changes with process conditions, generally it can acquire desired effectiveness in the range of 5Pa - 1000Pa. As for the distance (L11, L21, L51, L52, L61, L62) of the underside of a dielectric window, and the top face of a substrate, it is desirable to make it the range of 30mm - 120mm generally with relation, such as a plasma consistency, an oxidation rate, and thickness distribution homogeneity.

[0023] As described above, when changing the thickness of a dielectric window within the limits of predetermined, it is desirable to make the thickness into about  $\lambda_{\text{dag}}$  of the wavelength ( $\lambda_{\text{dag}}$ ) of the microwave in a dielectric / 4. Since field strength of microwave is \*\*\*\*(ed) according to the situation of the standing wave which exists there, if a center section is the optimal thickness, in the thin periphery section, a plasma consistency will become low. This is because field strength does not necessarily become strong in the thin part only by making thickness of a dielectric window thin selectively. Therefore, the thing [ as / in this invention ] which the thickness of a center section is specified and is established for the level difference of  $\lambda_{\text{dag}}/4$  of the wavelength of the microwave in a dielectric is effective. Even if arranged in the shape of [ of a concentric circle ] a ring, the range which gives the range or level difference which changes the thickness of a dielectric window was distributed suitably, and may be arranged.

[0024] In order to choose suitably from within the limits of 2GHz - 10GHz the frequency of the microwave supplied in order to generate the plasma of high density generally and to make it the plasma consistency [ directly under ] of a dielectric window reach the cut-off consistency of microwave, it is good to choose charge power from within the limits of 1 W/cm<sup>2</sup> - 5 W/cm<sup>2</sup> suitably preferably to the area under a dielectric window, and to perform a process. Although it changes as process gas with each processes, such as formation of deposition film (an insulator layer, the semi-conductor film, metal membrane, etc.), formation of the thin films (a silicon system semi-conductor thin film, a silicon compound system thin film, a metal thin film, metallic-compounds thin film, etc.) by the CVD method, etching on the front face of a substrate, ashing clearance of the organic component on a substrate front face, oxidation treatment on the front face of a substrate, and cleaning of the organic substance on the front face of a substrate, various well-known gas can be chosen suitably and can be used. For example, what is necessary is just to introduce one or more kinds of well-known gas more than a total of  $8.5 \times 10^{-2} \text{ Pa-m}^3/\text{sec}$  at least into a process.

[0025] What is necessary is just to choose it from within the limits of -40 degrees C - 600 degrees C suitably generally, although the support stage temperature of a substrate changes with each processes, such as etching and membrane formation. Especially the substrate made

into a processing object is not restricted, for example, not only a semi-conductor substrate but a glass substrate, a plastic plate, an AlTiC substrate, etc. can be used for it. As a dielectric which constitutes the introductory aperture of microwave, a mechanical strength is enough, and especially if dielectric loss is a very small ingredient so that the permeability of microwave may become sufficiently high, it will not be restricted, for example, a quartz, an alumina (sapphire), aluminium nitride, silicon nitride, a carbon fluoride polymer, etc. can be used.

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EXAMPLE

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[Example] Hereafter, the example of this invention is further explained to a detail with reference to a drawing.

(Example 1) Kr/O<sub>2</sub> plasma is generated using the equipment of this invention shown in drawing 1 and drawing 2, and measurement of the thickness of the oxide film of the processing wafer after oxidizing a silicon substrate directly is explained. Oxidation treatment of a silicon substrate which first is performed using the equipment shown in drawing 1 is explained. After installing the dielectric window 104 in the introductory aperture of microwave and setting a silicon substrate 113 in the vacuum processing container 101, microwave was outputted from the magnetron 106, the plasma was generated on condition that the following, and the thickness of the oxide film of the silicon substrate 113 after plasma oxidation was measured by the ellipsometer.

[0027] As a dielectric window 104, the quartz plate (a dielectric constant 3.8, dielectric loss  $<1.0 \times 10^{-4}$  @ 2.45GHz) with a diameter [ of 380mm (vacuum-housing side: 350mm) ] and a thickness of 50mm was installed. microwave — frequency: — 2.45GHz — output: — it was referred to as 2.5kW (about 2.6W/cm<sup>2</sup>), hot plate temperature was maintained at 400 degrees C, distance between the top face of a silicon substrate 113 and the underside of a dielectric window 104 (L11) was set to 60mm, and plasma treatment was performed, without impressing high frequency bias to the silicon substrate 113 on the substrate electrode 114. As gas for plasma excitation, 1.7X10<sup>-2</sup> Pa-m<sup>3</sup>/sec supply of 0.5 Pa-m<sup>3</sup>/sec and O<sub>2</sub> was carried out for Kr, by the pressure regulating valve 112, the pressure in the processing container 101 was adjusted to 133Pa, it discharged for 10 minutes, and plasma oxidation processing of a wafer was performed. Moreover, plasma treatment was performed on the same conditions as the above except having adjusted the pressure in the processing container 101 to 80Pa by the pressure regulating valve 112.

[0028] Consequently, distribution of the thickness of the silicon oxide formed on the substrate became concentric circular mostly. The average thickness of the direction of a path is shown in drawing 3. In the case of 80Pa, the periphery section on a substrate has thickness thicker than a center section, and drawing 3 shows that the oxidation rate of a center section is quicker in the case of 133Pa to a thing with a quick oxidation rate.

[0029] Next, using the equipment shown in drawing 2, on the same conditions as the case of the equipment shown in drawing 1, plasma oxidation processing of the silicon substrate 213 was carried out, and the thickness of an oxide film (oxidation silicone film) was measured by the ellipsometer. Consequently, distribution of the thickness of the silicon oxide formed on the substrate became concentric circular with homogeneity mostly. The average thickness of the direction of a path is shown in drawing 4. It turns out that that difference is small about this result although the oxidation rate of thickness distribution of the oxide film in 80Pa to the periphery section is still quicker than a center section as compared with drawing 3, and distribution homogeneity is improved. Moreover, on the whole, the formation rate of an oxide film is quick. While the power of microwave comes to be efficiently supplied to the plasma by changing the configuration of a dielectric window from this, it turns out that distribution homogeneity is improving. Also in 133Pa, on the whole, the oxidation rate is quick, and it can say that it is the same as that of the case where it is 80Pa.

[0030] (Example 2) Kr/O<sub>2</sub> plasma is generated using the equipment shown in drawing 5 , and measurement of the thickness of the oxide film of the processing wafer after oxidizing a silicon substrate directly is explained. On the same conditions as the case of the equipment shown in drawing 1 indicated in the example 1, plasma oxidation processing of the silicon substrate 513 was carried out, and the thickness of an oxide film was measured by the ellipsometer.

[0031] Consequently, distribution of the thickness of the silicon oxide formed on the substrate became concentric circular with homogeneity mostly. The average thickness of the direction of a path is shown in drawing 7 . This result is known by that the oxidation rate is [ the center section ] quick rather than the periphery section at the case of thickness distribution of the oxide film in 80Pa to drawing 3 , and reverse as compared with drawing 3 . This is because the consistency of the plasma to which the radius of a silicon substrate reaches a substrate in the range from 0mm to 30mm since the distance (L52) to a dielectric window (plasma production field) is short is higher than other range (distance: L51). Therefore, the distribution homogeneity of thickness is improvable by the membrane formation rate in the field rising by bringing the distance from the dielectric window underside by the side of a vacuum to a substrate close for every field, and adjusting the distance.

[0032] (Example 3) Kr/O<sub>2</sub> plasma is generated using the equipment shown in drawing 6 , and measurement of the thickness of the oxide film of the processing wafer after oxidizing a silicon substrate directly is explained. On the same conditions as the case of the equipment shown in drawing 1 indicated in the example 1, plasma oxidation processing of the silicon substrate 613 was carried out, and the thickness of an oxide film was measured by the ellipsometer.

[0033] Consequently, distribution of the thickness of the silicon oxide formed on the substrate became concentric circular with homogeneity mostly. The average thickness of the direction of a path is shown in drawing 8 . It turns out that it is improved in the direction in which the oxidation rate of a center section rises, and homogeneity is going up this result from thickness distribution of the oxide film in 80Pa as compared with drawing 3 . On the other hand, it is improved in the direction in which the oxidation rate of the periphery section rises conversely in 133Pa, and homogeneity is going up. Apparently, although this is contradictory to the result of the above-mentioned example, even if the dielectric window 104 ( drawing 1 ) of a flat-surface configuration is used for it in 133Pa high voltage conditions, it has the inclination which the plasma concentrates on a center section. However, like the result in an example 2, since it is far 5mm compared with the field (distance: L61) of others [ center section / substrate / distance / (L62) / to a dielectric window (plasma production field) ], it becomes thinner than the range of others [ consistency / of the plasma which reaches a substrate ], and it is thought that distribution has been improved. On the contrary, although the plasma tends to spread in the low voltage of 80Pa since the plasma consistency is thin, the plasma production in a field concave by making into a concave a part of field which a surface wave generates increases, and it thinks because the stability coupled modes of microwave stopped being influenced easily due to the flow and pressure requirement. Therefore, the breadth of the plasma was stopped, and near distribution came to be acquired when it is high voltage conditions.

[0034] As mentioned above, by performing concavo-convex processing to both sides of a dielectric window for every field, the power of microwave was intentionally centralized on this field, and generation of the homogeneous good plasma with little [ and ] pressure dependence was attained. Although plasma oxidation processing of the silicon substrate was carried out and the oxide film was formed in the above-mentioned example using drawing 1 and the microwave plasma treatment equipment shown in 2, 5, and 6, processes, such as an improvement and refining of membrane formation, etching, and a film presentation, and ashing, were able to be performed to the substrate which is a processed material in semi-conductor LSI production using well-known thin film formation gas, an etchant gas, ashing gas, etc. using the same plasma treatment equipment.

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[Translation done.]

**\* NOTICES \***

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**DESCRIPTION OF DRAWINGS**

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**[Brief Description of the Drawings]**

**[Drawing 1]** The typical sectional view showing the configuration of the outline of the microwave plasma treatment equipment concerning the first operation gestalt of this invention.

**[Drawing 2]** The typical sectional view showing the configuration of the outline of the microwave plasma treatment equipment concerning the second operation gestalt of this invention.

**[Drawing 3]** The graph which shows the average thickness of the direction of a path about the silicon oxide formed using the equipment shown in drawing 1 .

**[Drawing 4]** The graph which shows the average thickness of the direction of a path about the silicon oxide formed using the equipment shown in drawing 2 .

**[Drawing 5]** The typical sectional view showing the configuration of the outline of the microwave plasma treatment equipment concerning the third operation gestalt of this invention.

**[Drawing 6]** The typical sectional view showing the configuration of the outline of the microwave plasma treatment equipment concerning the fourth operation gestalt of this invention.

**[Drawing 7]** The graph which shows the average thickness of the direction of a path about the silicon oxide formed using the equipment shown in drawing 5 .

**[Drawing 8]** The graph which shows the average thickness of the direction of a path about the silicon oxide formed using the equipment shown in drawing 6 .

**[Description of Notations]**

101 Plasma Treatment Container 102 Coaxial Waveguide Converter and Antenna

103 Slot 104 Dielectric Plate

105 Plasma 106 Magnetron

107 Isolator 108 4E Tuner

109 Waveguide 110 Gas Supply Means

111 Exhaust Air Pump 112 Pressure Regulating Valve

113 Substrate 114 Substrate Electrode

115 RF Generator for Substrate Electrodes 116 Adjustment Machine for Substrate Electrodes

117 Sleeve 204 Dielectric Plate

213 Substrate L21 Distance between Dielectric Plate-Substrates

Dw Substrate range D2 Dielectric plate thickness modification range

504 Dielectric Plate 513 Substrate

L51 Distance between dielectric plate-substrates L52 Distance between dielectric plate-substrates (thickness modification section) D5 Dielectric plate thickness modification range

604 Dielectric Plate 613 Substrate

L61 Distance between dielectric plate-substrates L62 Distance between dielectric plate-substrates (configuration modification section) D6 dielectric thickness modification range

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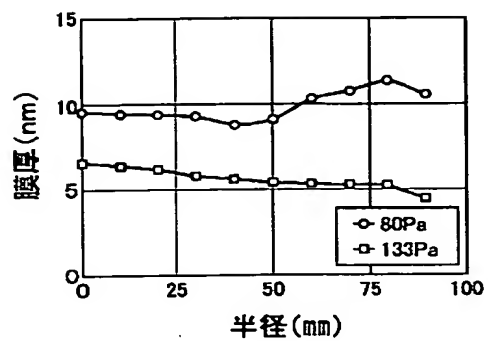
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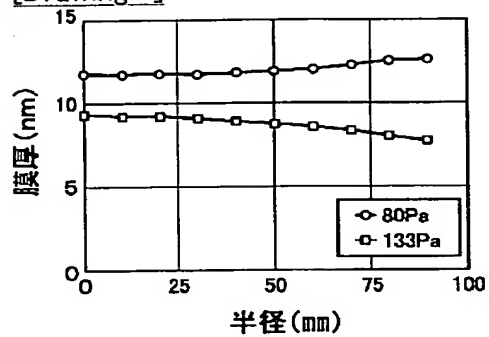
**3. In the drawings, any words are not translated.**

[Drawing\_1]

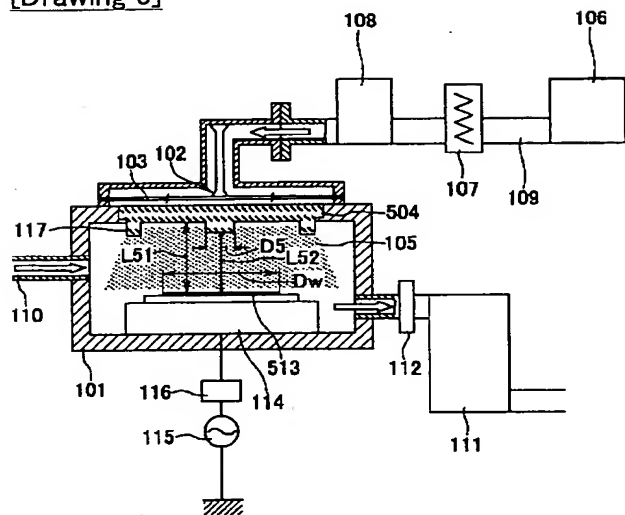




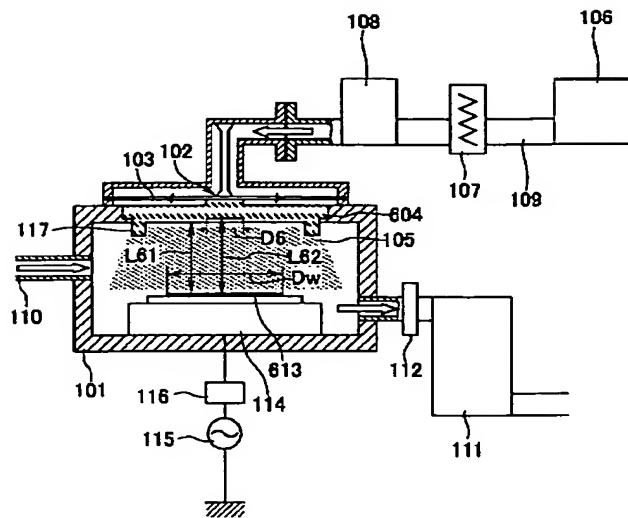
[Drawing 4]



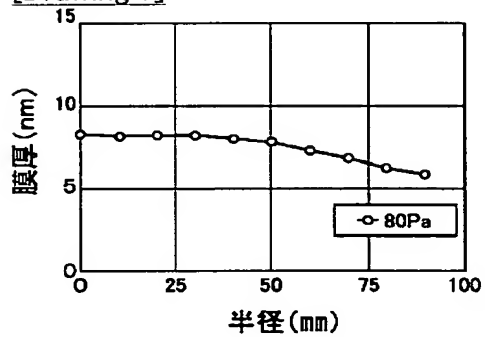
[Drawing 5]



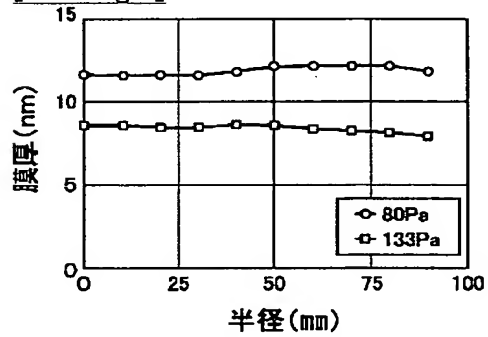
[Drawing 6]



[Drawing 7]



[Drawing 8]



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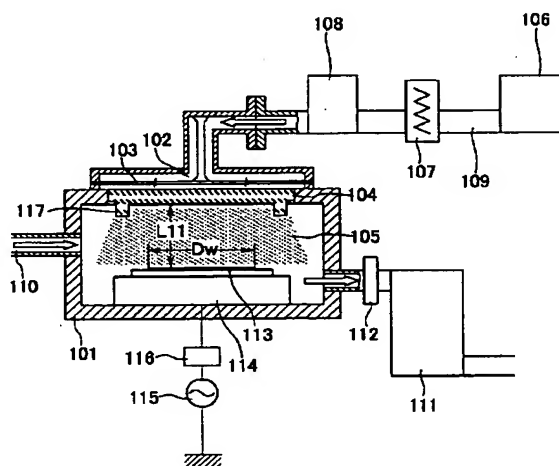
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(54) 【発明の名称】 マイクロ波プラズマ処理装置および処理方法

(57) 【要約】

【課題】 基板表面で均一なプラズマ密度を得、信頼性、安定性の高い高効率プラズマ処理を行うことができるマイクロ波プラズマ処理装置および処理方法の提供。

【解決手段】 基板表面の直上に設けられる誘電体窓として、外周部にリング状のスリーブを有し、さらに、中央部の表面形状や厚さが面内調整されたものを用いる。この面内調整は、基板内の半径の所定範囲に対応する誘電体窓の領域に凸部を設けたり、凸部の設けられた面と反対側の面の凸部対応領域に凹部を設けること等により段差を設けて行われる。誘電体窓の面内調整された領域の厚さが、誘電体内のマイクロ波の波長の1/4程度であり、また、面内調整領域が、誘電体窓の径方向に1/2波長の整数倍の直径で不連続に設けられる。



## 【特許請求の範囲】

【請求項 1】 マイクロ波プラズマ処理容器内を減圧するための排気手段と、該処理容器内にプラズマを励起するためのガスを供給するためのガス供給手段と、該処理容器の壁面に設けられたマイクロ波透過用誘電体窓と、該誘電体窓のマイクロ波導入側に設けられたアンテナ手段と、該アンテナ手段の上流側に設けられたマイクロ波発生手段とを備え、該誘電体窓に対向して該処理容器内に基板が設置されるように構成されているマイクロ波プラズマ処理装置において、該基板表面の直上に設けられた該誘電体窓は、その処理容器側の面の外周部に、プラズマ励起領域が直接処理容器壁の金属表面と接触しないように、リング状のスリーブを有している事を特徴とするマイクロ波プラズマ処理装置。

【請求項 2】 前記基板表面の直上に設けられた誘電体窓は、さらに、その中央部の表面形状や厚さが面内調整されて、該基板内の半径の所定範囲に対応する領域がその他の領域と異なった厚さを有するように構成されている事を特徴とする請求項 1 記載のマイクロ波プラズマ処理装置。

【請求項 3】 前記基板表面の直上に設けられた誘電体窓は、さらに、その処理容器側の面およびマイクロ波導入側の面のうちの一方の面において、該基板内の半径の所定範囲に対応する領域に凸部を設けて、該基板内の半径の所定範囲に対応する領域の厚さがその他の領域の厚さより厚くなるように構成されたものであるか、または、該凸部の設けられた面と反対側の面の該凸部対応領域に凹部を設けて、該凸部と凹部との設けられた領域の厚さがその他の領域の厚さと同じになるように構成されたものである事を特徴とする請求項 1 記載のマイクロ波プラズマ処理装置。

【請求項 4】 前記基板表面の直上に設けられた誘電体窓に同心円状の段差を設けて、該基板表面から該誘電体窓の表面までの距離が基板内の半径の範囲によって異なるようにし、生成するプラズマの密度が該基板上で均一になるようにした事を特徴とする請求項 1 記載のマイクロ波プラズマ処理装置。

【請求項 5】 前記基板表面の直上に設けられた誘電体窓の同心円状の段差が、該誘電体窓の径方向に  $1/2$  波長の整数倍の直径で不連続に設けられている事を特徴とする請求項 4 記載のマイクロ波プラズマ処理装置。

【請求項 6】 前記基板表面の直上に設けられた誘電体窓が、中央部の異なった厚さを有する領域や、凸部を有する領域や、同心円状の段差を有する領域を有し、その領域の厚さが誘電体内のマイクロ波の波長の  $1/4$  程度である事を特徴とする請求項 2～5 のいずれかに記載のマイクロ波プラズマ処理装置。

【請求項 7】 マイクロ波プラズマ処理容器内にガス供給手段によってプラズマを励起するための原料ガスを供給し、排気ポンプにより原料および反応副生成ガスを排

気して容器内を減圧にし、マイクロ波発生手段により共振、増幅せしめたマイクロ波をアンテナ手段に導入してスロットを通して放射し、放射されたマイクロ波をマイクロ波透過窓を介して真空雰囲気下の該処理容器内へ導入し、このマイクロ波の作る電磁界によって処理容器内にプラズマを生成し、該誘電体窓に対向して設けられた基板をマイクロ波プラズマ処理する事からなり、該基板表面の直上に設けられた該誘電体窓として、その処理容器側の面の外周部に、プラズマ励起領域が直接処理容器壁の金属表面と接触しないように、リング状のスリーブを有しており、さらに、その中央部の表面形状や厚さが面内調整されて、該基板内の半径の所定範囲に対応する領域がその他の領域と異なった厚さを有するように構成されているか、または、その処理容器側の面およびマイクロ波導入側の面のうちの一方の面において、該基板内の半径の所定範囲に対応する領域に凸部を設けて、該基板内の半径の所定範囲に対応する領域の厚さがその他の領域の厚さより厚くなるように構成されているか、または、該凸部の設けられた面と反対側の面の該凸部対応領域に凹部を設けて、該凸部と凹部との設けられた領域の厚さがその他の領域の厚さと同じになるように構成されている誘電体窓を備えたプラズマ処理装置を用いてプラズマ処理を行う事を特徴とするマイクロ波プラズマ処理方法。

【請求項 8】 前記誘電体窓として、同心円状の段差を該誘電体窓の径方向に  $1/2$  波長の整数倍の直径で不連続に設けた誘電体窓を備えたプラズマ処理装置を用い、生成するプラズマの密度が基板上で均一になるようにしてプラズマ処理を行う事を特徴とする請求項 7 記載のマイクロ波プラズマ処理方法。

【請求項 9】 前記誘電体窓として、中央部の異なった厚さを有する領域や、凸部を有する領域や、同心円状の段差を有する領域を有し、その領域の厚さを誘電体内のマイクロ波の波長の  $1/4$  程度にした誘電体窓を備えたプラズマ処理装置を用いてプラズマ処理を行う事を特徴とする請求項 7 または 8 記載のマイクロ波プラズマ処理方法。

【請求項 10】 前記処理容器内の前記ガス圧は  $0.1 \text{ Pa} \sim 1000 \text{ Pa}$  であり、電極に印加されるマイクロ波の周波数は  $2 \text{ GHz} \sim 10 \text{ GHz}$  であることを特徴とする請求項 7～9 のいずれかに記載のマイクロ波プラズマ処理方法。

## 【発明の詳細な説明】

【0001】

【発明の属する技術分野】 本発明は、マイクロ波励起プラズマ処理装置（以下、マイクロ波プラズマ処理装置と称す。）およびこの装置を用いるプラズマ処理方法に係わり、特に、 $0.5 \text{ W/cm}^2 \sim 20 \text{ W/cm}^2$  の大電力密度のマイクロ波導入窓を有するマイクロ波プラズマ処理装置であって、半導体 LSI 作製における被処理物

である基板に成膜、エッチング、膜組成の改善・改質、アッシングを行うことのできるマイクロ波プラズマ処理装置、およびこの装置を用いるプラズマ処理方法に係わる。

【0002】

【従来の技術】近年、半導体LSIにおけるデバイスの微細化、ウェーハの大口径化に伴い、ウェーハの微細加工は枚葉処理が主流になっている。その中のCVDやエッチングやアッシングのプラズマ処理ではDCや高周波励起のプラズマ源が用いられている。また、マイクロ波を用いたプラズマ源ではECR（電子サイクロトロン共鳴）が用いられている。上記のように高周波やECRで励起されたプラズマの場合、高密度のプラズマを生成するためには磁場の印加が必要である上、大口径で均一なプラズマを生成することが困難であった。また、プラズマ電位が約20eVと高いために、チャンバ壁をスパッタリングして金属汚染が発生したり、さらに、フローティング基板に対するイオン照射エネルギーも10eV以上と高いために、基板にダメージを与えるといった問題もあった。

【0003】そこで、ラジアルラインスロットアンテナ（以下、RLSAと称す。）などのアンテナ手段を用い、スロットから誘電体を介してマイクロ波を真空雰囲気中に導入し、強いマイクロ波電界を作り出すことによって表面波プラズマを生成する方式が開発されている。例えば、特開2000-294548号公報には、誘電体窓の厚さを連続的に変えた方式が記載されている。この方式では、アンテナのスロットパターンにより円偏波マイクロ波を放射するので、大口径で均一なプラズマが生成でき、また、周波数が高いため、低温かつ高密度のプラズマを生成することができ、高速で良質なプラズマ処理が実現できるとされている。

【0004】

【発明が解決しようとする課題】前記特開2000-294548号公報記載の従来技術では、マイクロ波は、導波路をある特定モードで伝播し、アンテナ手段から放射されて真空容器内にマイクロ波電界を作り出し、それによってプラズマを形成しているが、プラズマが高密度になると、エネルギー吸収が起こると同時にプラズマ表面でマイクロ波は反射され、不特定多数のモードが誘電体を挟んだアンテナ表面とプラズマ励起部との間で発生する。このように誘電体窓の厚さを連続的に変え、プラズマ処理室側の面を錐状にしたものを用いる場合、モードの安定性等に問題がある。

【0005】この反射波は、アンテナ表面とプラズマ励起部との間を空洞共振器として減衰されるモードと増幅されるモードとに分かれる。しかし、この反射波が、導入されたマイクロ波と干渉して減衰すると、プラズマへのパワー供給が安定せず、プラズマは不安定になる。その結果、反射波をチューナーで抑え切れなかったり、常

にオートマッチングが大きく揺れてしまい、プラズマが点滅するといった問題もあった。

【0006】また、マイクロ波は周波数が高いため、プラズマのある一部が低インピーダンスになる程、パワーがその一部に集中する傾向がある。さらに、径方向には表面波モードが形成され、これも多数のモードが結合して最も安定する状態を取るが、経時変化によりプラズマインピーダンスのバランスが少しでも崩れると、モードジャンプを起こしてプラズマ分布の再現性がとれないといった問題があった。また、この表面波モードはプロセス圧力にも大きく依存し、低圧（5～100Pa程度）と高圧（100Pa～）とではプラズマ密度分布が中央部と外周部で逆転するといった現象がある。

【0007】本発明の課題は、上記従来技術の問題を解決することにより、基板表面で均一なプラズマ密度を得ることができ、信頼性、安定性の高い高効率プラズマ処理を行うことのできるマイクロ波プラズマ処理装置およびこの装置を用いる処理方法を提供することにある。

【0008】

【課題を解決するための手段】本発明のマイクロ波励起プラズマ処理装置は、マイクロ波プラズマ処理容器内を減圧するための排気手段と、該処理容器内にプラズマを励起するためのガスを供給するためのガス供給手段と、該処理容器の壁面に設けられたマイクロ波透過用誘電体窓と、該誘電体窓のマイクロ波導入側に設けられたアンテナ手段と、該アンテナ手段の上流側に設けられたマイクロ波発生手段とを備え、該誘電体窓に対向して該処理容器内に基板が設置されるように構成されているマイクロ波プラズマ処理装置において、該基板表面の直上に設けられた該誘電体窓が、その処理容器側の面の外周部に、プラズマ励起領域が直接処理容器壁の金属表面と接触しないように、リング状のスリーブを有しているものである。

【0009】本発明のマイクロ波励起プラズマ処理装置において、基板表面の直上に設けられた誘電体窓が、さらに、その中央部の表面形状や厚さが面内調整されて、該基板内の半径の所定範囲に対応する領域がその他の領域と異なった厚さを有するように構成されている事が好ましい。誘電体窓はまた、その処理容器側の面およびマイクロ波導入側の面のうちの一方の面において、該基板内の半径の所定範囲に対応する領域に凸部を設けて、該基板内の半径の所定範囲に対応する領域の厚さがその他の領域の厚さより厚くなるように構成されたものであるか、または、該凸部の設けられた面と反対側の面の該凸部対応領域に凹部を設けて、該凸部と凹部との設けられた領域の厚さがその他の領域の厚さと同じになるように構成されたものである事が好ましい。上記処理装置において、誘電体窓に同心円状の段差を設けて、基板表面から誘電体窓の表面までの距離が基板内の半径の範囲によって異なるようにし、生成するプラズマの密度が基板上

で均一になるようにする事が好ましい。

【0010】上記誘電体窓の同心円状の段差が、該誘電体窓の径方向に1/2波長の整数倍の直径で不連続に設けられている事が好ましい。また、誘電体窓が、中央部の異なった厚さを有する領域や、凸部を有する領域や、同心円状の段差を有する領域を有し、その領域の厚さが誘電体内のマイクロ波の波長の1/4程度である事が好ましい。本発明のマイクロ波プラズマ処理装置によれば、大口径の誘電体窓、例えば、直径250mm以上を有するか、または直径250mmの円と同等以上の面積を有する誘電体窓を用い、大電力密度のマイクロ波を導入する事が可能である。

【0011】本発明のマイクロ波プラズマ処理方法は、マイクロ波プラズマ処理容器内にガス供給手段によってプラズマを励起するための原料ガスを供給し、排気ポンプにより原料および反応副生成ガスを排気して容器内を減圧にし、マイクロ波発生手段により発振、増幅せしめたマイクロ波をアンテナ手段に導入してスロットを通して放射し、放射されたマイクロ波をマイクロ波透過窓を介して真空雰囲気下の該処理容器内へ導入し、このマイクロ波の作る電磁界によって処理容器内にプラズマを生成し、該誘電体窓に対向して設けられた基板をマイクロ波プラズマ処理する事からなり、上記したように構成された誘電体窓を備えたプラズマ処理装置を用いてプラズマ処理する。上記処理容器内のガス圧は0.1Pa~1000Paであり、電極に印加されるマイクロ波の周波数は2GHz~10GHzであることが好ましい。ガス圧が0.1Pa未満であり、また、1000Paを超えると放電開始及び維持が困難となる。また、周波数が2GHz未満であると所望のプラズマ密度が得られず、10GHzを超えると電力増幅のための設備が大がかりになるほか、その取り扱いに難がある。

【0012】本発明によれば、マイクロ波プラズマ処理装置において、上記したように誘電体窓の表面形状や厚さを面内調整し、供給するマイクロ波と反射波が共振器内で増幅される領域とそうでない領域とを形成する事で、パワーをその増幅される領域に効率的に集中させ、また、空間で安定する表面波モードを制限する事でモードジャンプの発生を抑制できるため、信頼性、安定性の高い高効率プロセスを行うことができる。また、プラズマは、誘電体窓の表面から僅か数ミリ以内離れた領域で励起され、拡散によって対向する基板上に到達する。この拡散によるプラズマ密度の減衰は略々距離の二乗に比例する。プラズマ密度の低い領域に対応する誘電体部分を基板側に近づけるように誘電体窓の形状に段差をつける事により、基板表面で均一なプラズマ密度を得る事が出来る。

【0013】

【発明の実施の形態】以下、本発明の実施の形態に係るマイクロ波プラズマ処理装置を、図1、2、5、および

6を参照して説明する。図1は、本発明の第一実施態様として、RLSAを用いた半導体基板用マイクロ波プラズマ処理装置において、外周部にリング状のスリーブを有するマイクロ波透過窓を備えた装置の概略の構成を示す断面図である。

【0014】図1において、101はプラズマ処理を行うための処理容器、102は同軸導波交換器およびアンテナ手段、103はマイクロ波を放射するスロット、104はマイクロ波透過用誘電体窓、105はエッチングや成膜を行うために基板上方にマイクロ波電界により形成されたプラズマ、106はマイクロ波を発振するマグネトロン、107はアイソレータ、108は4Eチューナー、109は導波管、110はプラズマ形成用ガスの供給手段、111は排気ポンプ、112は容器101内の圧力を調整する圧力調整弁、113はプラズマ処理をされる基板、114は基板を保持する電極、115は基板電極114および基板113に必要な応じて高周波を印加するための高周波電源、116は高周波のインピーダンス調整をとるための整合器である。誘電体窓104の外周部、すなわち中央部から離れた部分には、プラズマ励起領域が直接処理容器壁の金属表面と接触しないようにリング状のスリーブ117が形成されている。

【0015】以下、図1に示す装置を用いて行うプラズマ処理方法についての概要を説明する。処理容器101内にガス供給手段110によってプラズマ105を励起させるためのガスを供給し、排気ポンプ111を動作させ、原料および反応副生成ガスを排気して処理容器101内を減圧にし、処理容器101内のプロセス圧力を圧力調整弁112によって調整する。マグネトロン106で発振、増幅されたマイクロ波は4Eチューナー108を通してアンテナ102に導入され、スロット103から放射される。このとき、反射波は4Eチューナー108によって処理容器101側へと戻されるが、調整しきれない反射波についてはアイソレータ107で吸収し、マグネトロン106へ戻ることを防いでいる。スロット103から放射されたマイクロ波は誘電体窓104を介して真空雰囲気下の処理容器101の内部へ導入され、このマイクロ波の作る電磁界によって処理容器101内にプラズマ105を形成する。

【0016】形成されたプラズマ105の密度が誘電体窓104の近傍でマイクロ波のカットオフ密度を越えると、マイクロ波の侵入長は数ミリとなってプラズマ中の数ミリの範囲において一部のエネルギーがプラズマ105に吸収され残りは反射される。生成されたプラズマ105の密度分布は、スロットパターンによっては平面で均一に調整することができるが、その時の処理容器101内の圧力や誘電体窓104の形状にも大きく依存する。このようにして生成されたプラズマ105は拡散によって基板113へ到達し、基板113に対して所望のプラズマ処理を施すことができる。

【0017】図2は、本発明の第二実施態様として、R L S Aを用いた半導体基板用マイクロ波プラズマ処理装置の構成において、アンテナ手段側の面に凸部を設けたマイクロ波透過窓を備えた装置の概略の構成を示す断面図である。この装置においては、マイクロ波の導入窓を構成する誘電体窓204として、同心円の領域、すなわち、円形の誘電体窓の中心から所定の等距離までの領域において大気側（マイクロ波導入側）の表面に凸部（直径：D2）を設けて、その部分の厚さを変えた誘電体窓を用いている。その他の構成は図1に示すものと同じ構成であり、図中の符号については、特に断らない限り、図1と同じ符号は同じ構成を示す。

【0018】マイクロ波の導入窓である誘電体窓204は、誘電体窓104と同様の材質のものから作製され得る。厚さ50mmの石英板を用いる場合、例えば、 $\phi = 95\text{ mm}$ までの範囲（D2）の領域において誘電体窓204の大気側を凸型にし、その凸型部分の厚さを60mmにしてある。例えば、直径（Dw）200mmのシリコン基板の直上にある誘電体窓の厚さは、基板の半径が0mmから47.5mmまでの範囲（D2 X 1/2）の領域においてその直上に位置する領域の厚さが60mmになり、その他の領域における厚さが50mmになる。

【0019】図5は、本発明の第三実施態様として、R L S Aを用いた半導体基板用マイクロ波プラズマ処理装置の構成において、処理容器101側の面に凸部を設けたマイクロ波透過窓を備えた装置の概略の構成を示す断面図である。この装置においては、マイクロ波の導入窓を構成する誘電体窓504として、同心円の領域、すなわち誘電体窓の中心から所定の等距離までの領域において図2の場合とは逆に真空側の表面に凸部（直径：D5）を設けて、その部分の厚さを変えた誘電体窓を用いている。その他の構成は図1に示すものと同じ構成であり、図中の符号については、特に断らない限り、図1と同じ符号は同じ構成を示す。

【0020】マイクロ波の導入窓である誘電体窓504は、誘電体窓104と同様の材質のものから作製され得る。厚さ44mmの石英板を用いる場合、例えば、 $\phi = 60\text{ mm}$ までの範囲（D5）の領域において誘電体窓504の真空側を凸型にし、その凸型部分の厚さを60mmにしてある。例えば、直径（Dw）200mmのシリコン基板の直上にある誘電体窓の厚さは、基板の半径が0mmから30mmまでの範囲（D5 X 1/2）の領域においてその直上に位置する領域の厚さが60mmになり、その他の領域における厚さが44mmになる。また、基板の半径が0mmから30mmまでの領域（D5 X 1/2）において、基板から誘電体板までの距離（L52）を40mmとし、その他の領域においてはその距離（L51）を56mmとしてある。

【0021】図6は、本発明の第四実施態様として、R L S Aを用いた半導体基板用マイクロ波プラズマ処理装

置の構成において、処理容器101側の面に凸部を設け、かつ、大気側の面で該凸部に対応する領域に凹部を設けたマイクロ波透過窓を備えた装置の概略の構成を示す断面図である。この装置においては、マイクロ波の導入窓を構成する誘電体窓604として、同心円の領域、すなわち誘電体窓の中心から所定の等距離までの領域においてマイクロ波導入側の表面に凸部、真空側の表面に凹部を設けるように加工し、誘電体窓自体の厚さがどの領域においても同じ厚さになるように構成した誘電体窓を用いている。その他の構成は図1に示すものと同じ構成であり、図中の符号については、特に断らない限り、図1と同じ符号は同じ構成を示す。

【0022】マイクロ波の導入窓である誘電体窓604は、誘電体窓104と同様の材質のものから作製され得る。厚さ50mmの石英板を用いる場合、例えば、 $\phi = 60\text{ mm}$ までの範囲（D6）の領域において誘電体窓604の真空側を凹型にし、基板613から直径（Dw）200mmの基板の直上にある誘電体窓までの距離については、基板の半径が0mmから30mmまでの範囲（D6）の領域においてはその距離（L62）を65mmとし、その他の領域においてはその距離（L61）を60mmとしてある。上記プラズマ処理容器内の圧力は、プロセス条件により異なるが、一般に、5Pa～1000Paの範囲において所望の効果を得ることができ。誘電体窓の下面と基板の上面との距離（L11、L21、L51、L52、L61、L62）は、プラズマ密度、酸化速度、膜厚分布均一性等の関係により、一般に、30mm～120mmの範囲にすることが好ましい。

【0023】上記したように誘電体窓の厚さを所定の範囲内で変える場合は、その厚さを誘電体内のマイクロ波の波長（ $\lambda g$ ）の $\lambda g / 4$ 程度にする事が望ましい。マイクロ波の電界強度はそこに存在する定在波の状況により交播するので、中央部が最適厚さであれば、薄い外周部ではプラズマ密度が低くなってしまふ。これは、誘電体窓の厚さを単に部分的に薄くしただけではその薄い部分で電界強度が強くなるとは限らないからである。そのために、本発明におけるように、中央部の厚さを規定して、誘電体内のマイクロ波の波長の $\lambda g / 4$ の段差を設けることが効果的である。誘電体窓の厚さを変える範囲または段差をつける範囲は、同心円のリング状に配置されたものであっても、または適宜分布させて配置されたものでも良い。

【0024】高密度のプラズマを生成するためには、投入するマイクロ波の周波数を、一般に、2GHz～10GHzの範囲内から適宜選択し、また、誘電体窓の直下のプラズマ密度がマイクロ波のカットオフ密度に達するようにするためには、投入電力を、誘電体窓下面の面積に対して、好ましくは $1\text{ W/cm}^2 \sim 5\text{ W/cm}^2$ の範囲内から適宜選択してプロセスを行うのがよい。プロセ



スガスとしては、堆積膜（絶縁膜、半導体膜、金属膜等）の形成、CVD法による薄膜（シリコン系半導体薄膜、シリコン化合物系薄膜、金属薄膜、金属化合物薄膜等）の形成、基板表面のエッチング、基板表面上の有機成分のアッシング除去、基板表面の酸化処理、基板表面の有機物のクリーニング等の各プロセスによって異なるが、公知の各種ガスを適宜選択して用いることができる。例えば、一種類以上の公知のガスをプロセス中に少なくとも合計 $8.5 \times 10^{-2} \text{ Pa} \cdot \text{m}^3 / \text{sec}$ 以上導入すればよい。

【0025】基板の支持ステージ温度は、エッチングや成膜等の各プロセスによって異なるが、一般に、 $-40^\circ\text{C} \sim 600^\circ\text{C}$ の範囲内から適宜選択すればよい。処理対象とする基板は、特に制限されず、例えば、半導体基板に限らず、ガラス基板、プラスチック基板、AlTiC基板等を使用できる。マイクロ波の導入窓を構成する誘電体としては、機械的強度が十分で、マイクロ波の透過率が十分高くなるように誘電損失が非常に小さい材料であれば特に制限されず、例えば、石英、アルミナ（サファイア）、窒化アルミニウム、窒化シリコン、フッ化炭素ポリマー等を用いることができる。

【0026】

【実施例】以下、本発明の実施例を図面を参照してさらに詳細に説明する。

（実施例1）図1および図2に示す本発明の装置を用いてKr/O<sub>2</sub>プラズマを生成し、シリコン基板を直接酸化処理した後の処理ウェーハの酸化膜の厚さの測定について説明する。はじめに、図1に示す装置を用いて行うシリコン基板の酸化処理について説明する。マイクロ波の導入窓に誘電体窓104を設置し、シリコン基板113を真空処理容器101内にセットした後、マグネトロン106からマイクロ波を出力して下記の条件でプラズマを生成し、プラズマ酸化後のシリコン基板113の酸化膜の厚さをエリブソメータにより測定した。

【0027】誘電体窓104として、直径380mm（真空容器側：350mm）、厚さ50mmの石英板（誘電率3.8、誘電損失 $<1.0 \times 10^{-4}$  @ 2.45GHz）を設置した。マイクロ波は周波数：2.45GHzで出力：2.5kW（約2.6W/cm<sup>2</sup>）とし、ホットプレート温度を400℃に維持し、シリコン基板113の上面と誘電体窓104の下面との間の距離（L11）を60mmとして、基板電極114上にあるシリコン基板113には高周波バイアスを印加することなく、プラズマ処理を行った。プラズマ励起用ガスとして、Krを $0.5 \text{ Pa} \cdot \text{m}^3 / \text{sec}$ 、O<sub>2</sub>を $1.7 \times 10^{-2} \text{ Pa} \cdot \text{m}^3 / \text{sec}$ 供給し、圧力調整弁112によって処理容器101内の圧力を133Paに調整し、10分間放電して、ウェーハのプラズマ酸化処理を行った。また、圧力調整弁112によって処理容器101内の圧力を80Paに調整したこと以外は、上記と同

じ条件でプラズマ処理を行った。

【0028】その結果、基板上に形成されたシリコン酸化膜の厚さの分布はほぼ同心円状となった。図3にその径方向の平均厚さを示す。図3から、80Paの場合は、基板上的外周部が中央部よりも膜厚が厚く、酸化速度が速いのに対し、133Paの場合は、中央部の酸化速度の方が速いという事がわかる。

【0029】次に、図2に示す装置を用いて、図1に示す装置の場合と同様の条件で、シリコン基板213をプラズマ酸化処理し、酸化膜（酸化シリコン膜）の厚さをエリブソメータにより測定した。その結果、基板上に形成されたシリコン酸化膜の厚さの分布はほぼ同心円状に均一となった。図4にその径方向の平均厚さを示す。この結果を図3と比較すると、80Paの場合の酸化膜の膜厚分布から、外周部は依然中央部よりも酸化速度は速いがその差は小さくなっており、また、分布均一性が改善されていることがわかる。また、全体的に酸化膜の形成速度が速くなっている。このことから、誘電体窓の形状を変更する事でマイクロ波のパワーが効率的にプラズマに供給されるようになるとともに、分布均一性が向上している事がわかる。133Paの場合も、全体的に酸化速度が速くなっており、80Paの場合と同様のことがいえる。

【0030】（実施例2）図5に示す装置を用いてKr/O<sub>2</sub>プラズマを生成し、シリコン基板を直接酸化処理した後の処理ウェーハの酸化膜の厚さの測定について説明する。実施例1に記載した図1に示す装置の場合と同様の条件で、シリコン基板513をプラズマ酸化処理し、酸化膜の厚さをエリブソメータにより測定した。

【0031】その結果、基板上に形成されたシリコン酸化膜の厚さの分布はほぼ同心円状に均一となった。図7にその径方向の平均厚さを示す。この結果を図3と比較すると、80Paの場合の酸化膜の膜厚分布から、図3の場合と逆に中央部が外周部よりも酸化速度が速くなっていることがわかる。これは、シリコン基板の半径が0mmから30mmまでの範囲において、誘電体窓（プラズマ生成領域）までの距離（L52）が短いために基板に到達するプラズマの密度が他の範囲（距離：L51）より高いためである。よって、領域ごとに真空側の誘電体窓下面から基板までの距離を近づける事でその領域での成膜速度が上昇し、また、その距離を調整する事で膜厚の分布均一性を改善する事が出来る。

【0032】（実施例3）図6に示す装置を用いてKr/O<sub>2</sub>プラズマを生成し、シリコン基板を直接酸化処理した後の処理ウェーハの酸化膜の厚さの測定について説明する。実施例1に記載した図1に示す装置の場合と同様の条件で、シリコン基板613をプラズマ酸化処理し、酸化膜の厚さをエリブソメータにより測定した。

【0033】その結果、基板上に形成されたシリコン酸化膜の厚さの分布はほぼ同心円状に均一となった。図8

にその径方向の平均厚さを示す。この結果を図3と比較すると、80Paの場合の酸化膜の膜厚分布から、中央部の酸化速度が上昇する方向に改善され、また、均一性が上がっている事がわかる。一方、133Paにおいては逆に外周部の酸化速度が上昇する方向に改善され、また、均一性が上がっている。これは、一見、上記実施例の結果と矛盾するが、133Paの高圧条件においては平面形状の誘電体窓104(図1)を用いてもプラズマが中央部に集中する傾向がある。しかし、実施例2における結果のように基板中央部は誘電体窓(プラズマ生成領域)までの距離(L62)が他の領域(距離:L61)に比べて5mm違いのため、基板に到達するプラズマの密度が他の範囲より薄くなり、分布が改善されたと考えられる。逆に、80Paの低圧ではプラズマ密度が薄いためにプラズマは広がる傾向があるが、表面波の発生する面の一部を凹型にすることで凹型の領域でのプラズマ生成が多くなり、マイクロ波の安定結合モードが圧力条件により影響を受け難くなったためと考えられる。そのため、プラズマの広がりが抑えられ、高圧条件の場合に近い分布が得られるようになったのである。

【0034】上記の様に、領域ごとに誘電体窓の両面に凹凸加工を施す事で、この領域にマイクロ波のパワーを意図的に集中させ、圧力依存が少なくかつ均一性の良いプラズマの生成が可能になった。上記実施例では、図1、2、5および6に示すマイクロ波プラズマ処理装置を用いて、シリコン基板をプラズマ酸化処理し、酸化膜を形成したが、同じプラズマ処理装置を用いて、半導体LSI作製における被処理物である基板に対して、成膜、エッチング、膜組成の改善・改質、アッシング等の工程を、公知の薄膜形成ガス、エッチャントガス、アッシングガス等を用いて行う事ができた。

【0035】

【発明の効果】以上詳細に説明したように、本発明によれば、マイクロ波プラズマ処理装置において、誘電体窓の表面形状や誘電体窓の厚さを面内調整し、供給するマイクロ波と反射波が共振器内で増幅される領域とそうでない領域を形成する事で、パワーをその増幅される領域に効率的に集中させることができるため、また、空間で安定する表面波モードを制限する事でモードジャンプの発生を抑制できるため、信頼性、安定性の高い高効率プロセスを行うことができる。また、プラズマは誘電体窓から数ミリ以内の領域で励起され、拡散によって対向する基板上に到達する。この拡散によるプラズマ密度の減衰は略々距離の二乗に比例する。密度の低い領域の誘電体窓を基板側に近づくように段差をつける事により基板表面で均一なプラズマ密度を得る事が出来る。

【図面の簡単な説明】

【図1】 本発明の第一実施形態に係るマイクロ波プラズマ処理装置の概略の構成を示す模式的断面図。

【図2】 本発明の第二実施形態に係るマイクロ波プラズマ処理装置の概略の構成を示す模式的断面図。

【図3】 図1に示す装置を用いて形成されたシリコン酸化膜について、その径方向の平均厚さを示すグラフ。

【図4】 図2に示す装置を用いて形成されたシリコン酸化膜について、その径方向の平均厚さを示すグラフ。

【図5】 本発明の第三実施形態に係るマイクロ波プラズマ処理装置の概略の構成を示す模式的断面図。

【図6】 本発明の第四実施形態に係るマイクロ波プラズマ処理装置の概略の構成を示す模式的断面図。

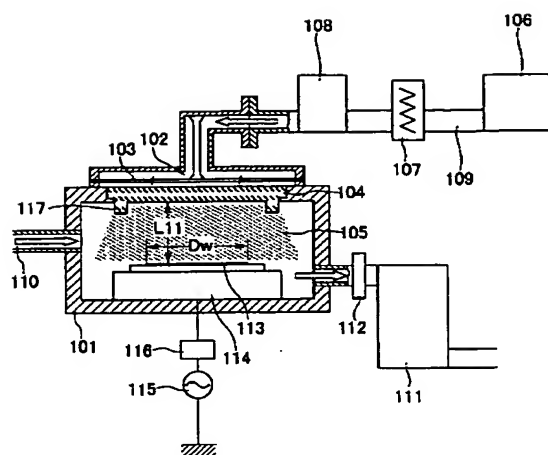
【図7】 図5に示す装置を用いて形成されたシリコン酸化膜について、その径方向の平均厚さを示すグラフ。

【図8】 図6に示す装置を用いて形成されたシリコン酸化膜について、その径方向の平均厚さを示すグラフ。

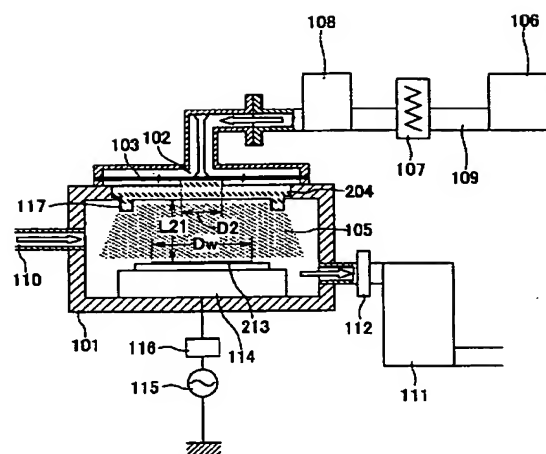
【符号の説明】

101	プラズマ処理容器	102	同軸導波変換器およびアンテナ
103	スロット	104	誘電体板
105	プラズマ	106	マグネトロン
107	アイソレータ	108	4Eチューナー
109	導波管	110	ガス供給手段
111	排気ポンプ	112	圧力調整弁
113	基板	114	基板電極
115	基板電極用高周波電源	116	基板電極用整合器
117	スリーブ	204	誘電体板
213	基板	L21	誘電体板-基板間距離
Dw	基板範囲	D2	誘電体板厚さ変更範囲
504	誘電体板	513	基板
L51	誘電体板-基板間距離	L52	誘電体板-基板間距離(厚さ変更部)
D5	誘電体板厚さ変更範囲		
604	誘電体板	613	基板
L61	誘電体板-基板間距離	L62	誘電体板-基板間距離(形状変更部)
D6	誘電体厚さ変更範囲		

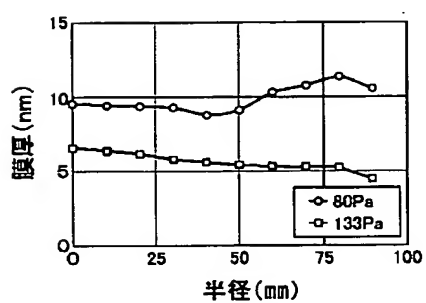
【図1】



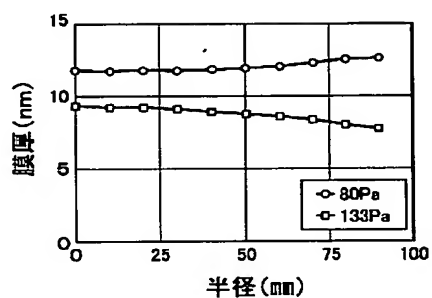
【図2】



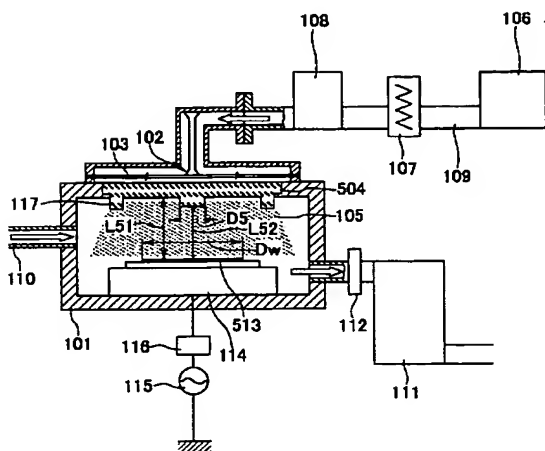
【図3】



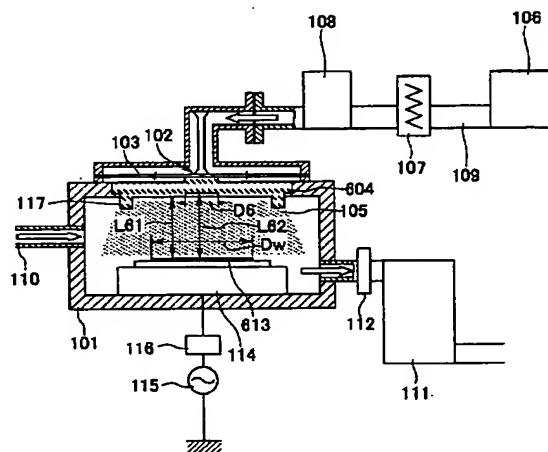
【図4】



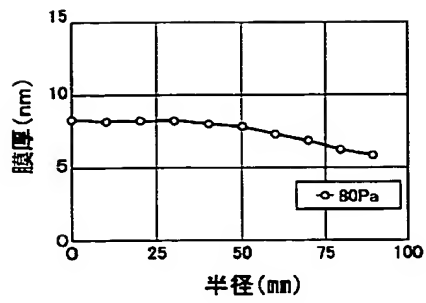
【図5】



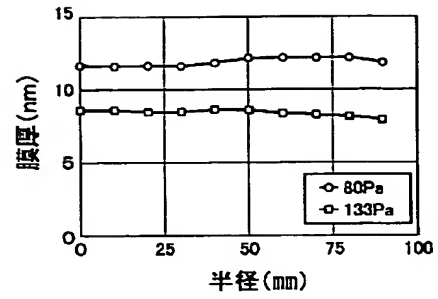
【図6】



【図7】



【図8】



フロントページの続き

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